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UNIVERSITY OF ALBERTA

Clastic Sediment Production and Diagenesis in Selected
Western North American Caves and Rockshelters

BY

Douglas Wayne Schnurrenberger

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of
the requirements for the degree of Doctor of Philosophy.

Departments of Anthropology and Geology

Edmonton, Alberta
Fall, 1991



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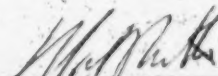
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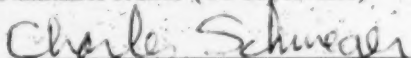
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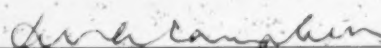
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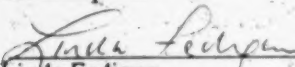
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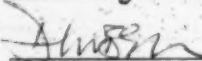
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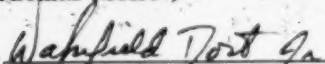

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Abstract

This dissertation presents investigations into the patterns of clastic sedimentation and diagenesis of coarse clastic sediments at 10 caves and rockshelters. All sites are located between lat. 45°N and lat. 67°N, in the western continental, cordilleran region of North America. These sites form a latitudinal transect (southern Montana, southern Alberta Rocky Mountains, northern Yukon) with decreasing mean annual temperature from south to north. Sites in the Pryor Mountains (southern Montana) form an altitudinal transect, with decreasing mean temperatures and frost-free season with increasing elevation. All sites lie in macroclimatic regions which experience a number of periods throughout the year in which exterior temperatures fluctuate over the 0° isotherm. These sites are examined as modern and Holocene analogues for clastic sedimentation and diagenesis in European late Pleistocene caves and rockshelters.

Modern and late Quaternary sediment accumulations are described (primary emphasis on coarse clastic products) for each site. An attempt is made to relate the production of sedimentary products within caves to variables of sedimentation both intrinsic and extrinsic to the site. In particular, the role of micro- and macroclimatic variation in producing different rates and kinds of sedimentation are assessed. Sites within a region are then compared in order to examine the role of micro- vs. macroclimatic variation in sediment production. Finally, sites are compared along the latitudinal transect to examine variable sedimentation patterns under very different macroclimatic regimes.

Results from this study contradict other studies, primarily from Europe, in ascribing local and intrinsic features of the bedrock, geomorphic position and microclimate, greater responsibility for variation in sediment textural and morphological parameters than that resulting from gross regional climatic differences. It is possible that the regional climate of individual sites played a much smaller role in producing textural variation within sediments than that due to more site-specific factors. These conclusions cast doubt on the ability to perform time-correlative studies on cave and rockshelter strata on the basis of presumed time-synchronous, regional fluctuations in climate. Extrapolations of regional climato-stratigraphic sequences to other, more distant regions, would logically be even more highly suspect.

Preface

In July, 1985 I accepted a job to teach for the University of Maryland, European Division. My family and I were excited about the position and I was at a logical point in my career to leave my graduate student days and start earning a living. At this point I had completed my candidacy examination, conducted my fieldwork, including all the necessary photographic documentation, performed all laboratory analyses, processed the lab data into tables and diagrams, drafted the majority of the necessary figures, and written at least rough drafts of the majority of my dissertation. I hoped to finish the first draft of the dissertation over the upcoming year and, hopefully, defend the following year.

While driving all our worldly belongings for storage in the Washington D.C. area, my wife, driving our VW van loaded with all our valuable personal things, was struck at high speed by a drunken driver, at around 3 A.M. on a rainy night on the interstate around Chicago. The van, including all its contents, was destroyed. Only my wife, thankfully wearing a seatbelt, remained within the van and suffered relatively minor injury.

Following the accident, holding our sleeping 1 year old child, I attempted to salvage what I could from the accident scene while the ambulance took my wife to the hospital. I was in a state of complete shock, seeing all our belongings, including books, papers, computer and household items strewn for about 100 meters in the high grass along the highway. As I had no place to put the items, the police borrowed the city pound van and we attempted to salvage what we could. I attempted to recover what I could, under the circumstances, gathered my wife from the hospital and found a nearby hotel where I slept until late the next day.

Several computer diskettes, containing text and data were recovered though they were so badly damaged the data was lost. I recovered only a few of my slides and negatives and most of these were also essentially useless. In the wind and rain I, as well as several helpful passerbys managed to recover some of our books and other reference material as well as wet, torn figures and diagrams, and hardcopy of my rough drafts.

At this point I felt my dissertation was a complete loss. I packed what we had recovered into a cardboard box and eventually took it to Europe with me. After about one year I got up the courage to look over the contents. Since that point I have tried to reconstruct a defensible dissertation from the remains.

In terms of irrevocably lost data was a notebook containing diagrams and data on 20 unexcavated caves and rockshelters, where I simply described the sites and sampled the surface sediment. I also had saved the sand fraction from all my sediment samples for mineralogical analysis. As these samples were stored in glass vials they were, for the most part, broken, making it pointless to examine the remaining vials. I also lost bits and pieces of other data, as indicated in the text.

Fortunately I did recover four notebooks containing much of the raw data from the sites discussed in this dissertation. Using this material I was able to start at square one, recalculating grain size diagrams, constructing tables and figures. Following my year of shell-shock I began to rewrite this dissertation, using the bits and pieces of rough drafts that remained.

Probably the most difficult part has been redoing all the work that I had finished before I left. Combining this psychological block with the uncertainty as to whether I really still had enough material to produce a legitimate dissertation has made the entire process even more difficult than it usually is to finish a Ph.D dissertation. I can only thank my dissertation advisors and committee members for their patience and support throughout this painful process.

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Chapter 1

Introduction

PURPOSE

This study investigates site formation processes and patterns of clastic sedimentation in a series of small caves and rockshelters located in western North America. The purpose of the study is to determine whether regional climate is an overriding factor in determining the character of sediment accumulations within caves and rockshelters, as held by some geoarchaeologists (e.g. Laville et al. 1980), or, whether, as argued by others, microenvironmental or non-climatic factors may play a greater role in deposition within a site (e.g. Farrand 1985). Although the sites investigated are not "typical" cave and rockshelter sites, they do illuminate the great diversity in sedimentary products that accumulate under very different and sometimes enigmatic sedimentary environments.

The goals of this research are two-fold; 1) to assess current methods of rockshelter sedimentological analyses in terms of their utility and validity as Quaternary paleoclimatic-climatostratigraphic tools, and 2) to apply these methods to the analysis of late Quaternary rockshelter fills in selected North American sites. This goal will be approached through; 1) documentation of patterns of modern clastic sedimentation in rockshelters in selected study sites in western North America and, 2) the examination of past sedimentation patterns in excavated late Quaternary rockshelter fills.

BACKGROUND

Rockshelters, including both true rockshelters and entrance portions of caves, are widely recognized as important repositories of archaeological information. In carbonate rock formations, rockshelters commonly offer a favorable preservation environment due to generally minimal erosion and a chemical weathering environment resulting in close associations of hominid artifactual and paleontological remains. Furthermore, several decades of sedimentological research (primarily in Europe) offers promise that rockshelters can yield sensitive paleoclimatic information in sufficient detail to allow regional and inter-regional climato-stratigraphic correlation between sites (Colcutt 1979, Laville 1976, Laville et al. 1980)).

Recognition that paleoclimate could be reconstructed from rockshelter sediments was initially formulated by Lais (1941) working in southern German Paleolithic sites. Subsequent European researchers have elaborated upon Lais's suggestion and applied his methods to numerous caves and rockshelters throughout Europe and the Middle East (e.g. Bonifay 1956, 1962; Laville 1975, 1976; Goldberg 1971; Farrand 1975, 1979; Madeyska 1982; Texier 1973). Modified versions have been utilized elsewhere (South Africa: Butzer 1973, Butzer et al. 1978; North America: Ahler 1976), but to a more limited extent.

In general, the methodology of "classical" European cave sedimentology is predicated on the assumption that "the degree of cryoclastism to be attributed to any abri sediment is at least roughly measurable in terms of its texture" (Laville et al. 1980: 53); as the ratio of coarse (>1 cm) to fine sediment increases, the climate is assumed to have become progressively cooler. The end-member facies in this continuum is an open-work (clast-supported) *éboulis sec*, consisting of relatively large, angular clasts, the result of a very cold and dry climate.

Secondary characteristics of individual stratigraphic units are used to modify, or refine the interpretation based on textural grounds alone. These include clast morphology (e.g. rounding and particular shapes believed to be indicative of particular climates), clast porosity, concretions, erosional unconformities in association with evidence of pedogenesis, evidence for cryoturbation or solifluction and evidence for fluvial transport

either via streams or unintegrated runoff. The climatic interpretations of these characteristics employed by a variety of authors are presented in Table 1.

In addition to paleoclimatic reconstruction, the European methodology has been used to permit the relative age estimations of included archaeological materials (a particularly significant aspect in light of the general paucity of radiometric dates from European Pleistocene rockshelter fills).

Laville (Laville 1975; Laville et al. 1980) has carried the climatostratigraphic correlation of sedimentary units in southwestern France to a high degree of specificity. Using major unconformities as indicators of interstadials, and combining cave sedimentological information with that derived from palynological and paleontological investigations, Laville has constructed a generalized climatostratigraphic scheme for southwestern France that combines the climatostratigraphic schemes from several overlapping rockshelters (Figure 1). This method holds greatest promise for European Middle Paleolithic sites, many of which are older than the conventional upper limit for ^{14}C dating. The method has also proven useful for Lower Paleolithic sites either too young for the ^{40}K - ^{40}Ar method, or lacking appropriate materials to date.

Using a similar methodology, other researchers have attempted similar climatostratigraphic correlation for rockshelter fills in the Middle East (Goldberg 1971), and South Africa (Butzer et al. 1978). Most researchers correlate their climatostratigraphic units to glacial/interglacial sequences, extending alpine glacial sequences to southwestern France (Laville 1975), and Spain (Straus et al. 1981). Butzer has attempted to correlate climatostratigraphic units from either individual rockshelters (Butzer et al. 1978) or a number of sites within a region (Butzer 1981) with the marine isotopic stages of Shackleton (1975).

Using a more explicitly geomorphological approach, several workers have attempted climatostratigraphic subdivision of rockshelter sediments by linking changes in sediment parameters to external (to the cave) climatically-induced geomorphological changes (Butzer 1981, McMillan and Klippel 1981, Ahler 1976, see also Farrand 1979). With the exception of Butzer's (1981) study of Pleistocene rockshelter sediments in northern Spain, these studies are focused primarily on Holocene climatic change.

Cave sedimentological studies provide, as in the sedimentological study of any archaeological site, important evidence for geomorphological context, a critical step in the interpretation of the context of the contained artifacts (Butzer 1981). More importantly for this study, cave sedimentological studies provide the possibility of temporal correlation of sites within, or between regions by reference to regional and extra-regional climatostratigraphic schemes. The extent to which these studies will be successful depends upon the level of understanding of cave and rockshelter sedimentary processes, either through empirically based studies such as the present one, or further experimental work.

SEDIMENTARY FACIES IN CAVES AND ROCKSHELTERS

Although there are numerous archaeological investigations of rockshelter sediments, the geoarchaeological literature documenting sedimentary facies typical of this very localized but heterogeneous depositional environment are notably lacking.

Rockshelters possess little economic value, and little preservation potential for the geologic record, so sedimentologists have generally shown little interest in them. Speleologists are by and large unconcerned with sediment accumulations in the entrance facies (facies in the sense of Jennings 1971), and have not pursued their study. Archaeologists have (more so in North America) either ignored the detailed study of sediments comprising rockshelter archaeological sites, or have been content with a simple detailing of differences in color and texture in stratigraphic units for temporal separation of archaeological assemblages.

The description of sedimentary facies common to rockshelters is complicated by the fact that the depositional environment, though spatially small, is extremely complex, forming a

junction between a potentially wide variety of depositional and diagenetic processes. Typically, sediments may be derived by gravity fall from the walls and ceilings, by debris flows either out of or into the rockshelter, by introduction of aeolian or fluvial sediment either from within or outside the rockshelter, and the introduction and syn- and post-depositional disturbance of sediment by a variety of biologic agencies, including, perhaps most significantly, humans.

Thus the reconstruction of regional climate from variations in the texture, morphology, and sedimentary structures within a rockshelter, is complicated by the numerous potential sedimentary processes and the degree to which microenvironmental factors have priority over regional climatic factors. In addition, the role of animals, particularly humans, in drastically altering the rockshelter microenvironment has been only briefly acknowledged (Colcutt 1979).

As will be demonstrated in the following chapter, the basic assumptions employed in the reconstruction of the climate of formation of various lithostratigraphic units within rockshelters are not well-founded in either empirical or experimental research. Several experimental lines of research argue for an extremely complex relationship between climate and clastic sediment production. To date, little empirical evidence of clastic sedimentation in rockshelters in cold climates has been reported. Modern analogues for rockshelter sedimentation under periglacial or very cold climates must therefore be identified before reconstruction of sedimentation in European Paleolithic sites can be pursued with confidence.

Several researchers have questioned the validity of the largely intuitively-based cave sedimentological method (see Farrand 1985; Colcutt 1979). It is telling that although a very detailed climatostratigraphic sequence has been constructed for the mid to late Pleistocene of southwestern France (Laville et al. 1980), other Quaternary scientists have largely ignored this work. This is surprising because for many terrestrial regions outside the glacial limits where sufficient palynological work has not been conducted, these climatostratigraphic sequences provide a potential for comparison to the detailed marine climatostratigraphic sequences.

It is with these considerations in mind that the present study was undertaken. If a viable method of climatic reconstruction for rockshelter sediments can be developed, it would have significant implications both for archaeological research (estimation of relative age and regional environmental conditions) and Quaternary geological research (identification of terrestrial climatic change).

RESEARCH DESIGN

In order to evaluate the role of climate in site formation, North American caves and rockshelters along altitudinal and latitudinal transects were investigated. High latitude caves and rockshelters in North America, which presumably would, at least in a gross fashion, reflect climatic gradients. Although it was not possible to investigate all combinations of temperature and humidity this study provides a useful first look at clastic sedimentation processes for sites located in continental cold to continental arctic climatic regimes.

As much as possible, it was decided to collect data that could meaningfully be compared to cave sedimentological research elsewhere. As Colcutt (1979) points out, several alternative methods of cave sedimentological field and laboratory research methodology exist (see Chapter 2). In this study, an attempt has been made to follow the methods outlined most clearly by Laville (Laville 1975, Laville et al. 1980).

PREVIOUS RESEARCH

Since the 1950's, researchers in Europe have attempted to use variations in the texture, morphology and geochemistry of the sediments to infer the past climate under which cave and rockshelter sediments accumulated (e.g. Bonifay 1956, Lais 1941). This line of research has culminated in a study of sites in southwestern France, where it is argued that analysis of cave and rockshelter sediments, in combination with palynological and paleontological investigations, is capable of yielding a very detailed micropaleoclimatological history for specific sites (Laville et al. 1980). Furthermore, it is argued, individual sites can then be fitted into a master micropaleoclimatological scheme in order to establish the contemporaneity of individual stratigraphic units and their included archaeological and paleontological materials in much the same manner as dendrochronological comparisons are made.

This approach to the study of cave and rockshelter sediments, as exemplified by the work of Bonifay (1962) and Laville (1975) seeks to reconstruct past climate almost entirely in terms of processes internal to the site itself. This approach tends to view caves and rockshelters almost as closed systems (closed to other outside geomorphological agents) controlled only by the exterior, regional climate. Because the regional climate is seen as the primary geomorphological agent, sediment formation must, therefore, be controlled almost entirely by climate. For purposes of discussion, I term this approach the "closed system approach".

Other cave sedimentologists have sought to interpret past climate in terms of how changing external, geomorphic agencies, mediated by changing climate, have affected the quality and quantity of sediment introduction into prehistoric caves and rockshelters (e.g. Farrand 1975, Butzer 1981, McMillan and Klippel 1981, Ahler 1976). These studies attempt to infer past climatic change by discerning evidence for significant, climatically induced changes in the cave exterior geomorphic setting. An example would be major vegetative change resulting from increased or decreased rates of effective precipitation, with implications for altered rates of soil erosion and deposition. I term this approach the "open system approach". The present study makes no attempt to evaluate this particular line of research.

The goals in all cave sedimentological studies have included; 1) reconstruction of the genesis and sequence of formation of strata included within the site; 2) reconstruction of the environmental conditions prevailing during various episodes or periods of site formation; 3) dating of the strata by reference to regional or global climatostratigraphic frameworks that may or may not themselves be anchored with chronometric dates. This last goal is extremely important in that archaeological and paleontological materials in sediments dating from approximately 50,000 BP to 150-200,000 BP have proven difficult to date radiometrically. Thus, in many cases sedimentological studies of cave deposits have proven the only means of tying archaeological important sites to a chronometric framework (cf. Laville et al. 1980, Butzer 1981).

Outline of this Study

Chapter 2 reviews relevant published research in cave and rockshelter sedimentology. Variation in the frequency and intensity of freeze-thaw weathering is viewed by most researchers as the dominant factor producing variation in cave and rockshelter sediments. However, the approach is currently in a state of profound uncertainty; There are few well-founded interpretative principles, making the climatic reconstruction of largely physically weathered sediments a difficult task.

Chapter 3 outlines the rationale for site selection, and field and laboratory methods used in this study. In order to comprehend more fully the figures presented later, it is important for the reader to examine this chapter as certain distinctions commonly made here in the field of cave sedimentology differ somewhat from standard sedimentological practice. This

chapter also presents a generic cave/rockshelter model for viewing the the various sedimentary products and diagenetic processes operative in these environments.

Chapters 4-6 present the various caves and rockshelters that were examined for this study. No attempt is made necessarily to infer the climate of formation of the sediments contained within these shelters or to provide a detailed site history for each example.

Rather, the emphasis is primarily on comparing the sedimentary products at each site with the inferred climate under which they formed, either modern or late Quaternary, to the extent that data concerning past climates is available. The focus is therefore comparative, rather than site specific. At the end of each chapter an attempt is made to compare sites within nearby geographical areas and to explain the observed differences in sedimentary products.

Chapter 7 culminates with a comparison of the products and processes inferred for all the sites discussed in this study. As far as possible, the data presented in this study are then compared to data from other documented cave and rockshelter fills, particular those which accumulated sediment over the late Pleistocene. At this point the methods and assumptions of the cave sedimentological model, in particular the closed system model, are evaluated in light of the research presented in this study. The final section offers suggestions for undertaking future research.

Chapter 2

Review of Literature

INTRODUCTION

Inasmuch as the present study builds upon and critically evaluates previous work, it is useful to examine briefly some of the extant literature of cave sedimentology. An attempt is made to somewhat artificially place the studies into two categories, each reflecting very different assumptions concerning the formation of sedimentary deposits in rockshelters. Of course, in the absence of abundant studies of modern analogues for cave and rockshelter sedimentation, much of the interpretation of sediment formation must necessarily reflect a great deal about the interpreters' ideas and intuitive assumptions concerning the influence of various processes. The goal, however, of regional climatic reconstruction is the same in many of these studies and it is instructive to examine in some detail the means by which they reach a similar goal following diverse and often tortuous paths.

Finally, the more abundant, but even more heterogeneous literature on the physical weathering of rock is examined. Research in this field must ultimately form the basis for much of the interpretive basis of cave sedimentological methods. However, this field is currently in a state of flux, with most researchers advocating a return to fundamentals and the avoidance of sweeping generalizations, particularly regarding the efficacy freezing and thawing of water as a physical weathering process. Without a firm understanding of the influence of climatic variables (temperature and moisture) on the breakdown of rock under experimental or natural conditions, it will surely be impossible to relate sediment accumulations in caves and rockshelters to either the regional climate or the microclimate under which their deposits formed.

CAVE SEDIMENTOLOGICAL STUDIES

The primary goal of all the studies reviewed in this section was to place the sediments containing archaeological materials into a temporal framework, with or without the support of radiometric dating techniques; "The purpose of the sedimentological investigations... was to reconstruct the origin of the deposits from the point of view of climate changes taking place during their sedimentation, in order to arrive at a basis for chronological interpretation" (Madeyska 1982: 13). In the case of the European Paleolithic sites, the attempt has been made to reconstruct the regional climate under which sedimentary deposits were formed, and then to correlate individual strata to global and/or regional climato-stratigraphic frameworks established elsewhere (e.g. Laville and Hahn 1981). A subsidiary goal of all but a few of the studies, was to provide information for a detailed paleoenvironmental reconstruction, as this task is more suited to fossil pollen data or paleontological methods, often from contemporaneous sediments outside the cave.

ALTERNATIVE STRATEGIES TO THE RECONSTRUCTION OF CLIMATE

Closed System Approach

The "closed system approach" to the reconstruction of climate from rockshelter sediments assumes that the bulk of sediment within the shelter is autochthonous, and that sediment introduction from exterior geomorphic agents (aeolian processes, runoff, debris flow, etc.) was limited and, where present, easily identifiable. Under this assumption, all

variability in the texture, structure and geochemistry of the sediments must reflect conditions intrinsic to the site itself. As climate (either regional or micro-) is the only significant variable affecting the intrinsic production of sediment (if tectonic forces can be excluded), the climate of formation should be decipherable from variations in the sediments themselves. Since regional climate impinges on rockshelter climate, variation in texture, morphology, and diagenesis of clastic sediments is directly attributable to changes in regional climate. Because regional climate is the dominant factor creating variability in sediments, and the climate of formation can be determined by the application of a rigorous analytical procedure, it is possible to assign relative climatic terms to sediments in particular strata. It is therefore possible to erect a climatostratigraphic chart for individual sites. Since regional climate is assumed to work equally on all sites and no strata are missing, it is possible to make temporal correlations between sites in the absence of radiometric dates.

Unfortunately, the empirical or experimental evidence on which to base such a regional climatic sequence is not available. There have been no empirical studies of cave sedimentation under conditions analogous to Europe during the Pleistocene. Similarly, as discussed below, experimental research on rock disaggregation is not sufficiently advanced that sound interpretive principles can be derived. Interpretations are therefore intuitively based, with the addition of only limited, controversial experimental work on cryogenic clast production and morphology, such as that of Lautridou and Ozouf (1982).

Recent work by Farrand (1979, 1985) and others, has called into question the primacy of a cold climate as a prerequisite for the production of thick strata of clasts > ca. 1 cm. Farrand (1985) reports coarse textured sedimentary units from the Middle East which he feels are not distinguishable from the supposed cold climate sediments from rockshelters in the Perigord region of France. My own experience in Jordanian rockshelters and small caves supports Farrand's contention. Even in the warm, dry climate of this region, production of coarse, clastic limestone fragments takes place.

In addition the degree to which regional versus microclimatic factors dominate processes of site formation and alteration has not been substantiated. If in fact microenvironmental conditions may leave a stronger signature on rockshelter sediments in a particular site than regional climate, correlation within, and especially without a region would certainly be precluded. Again, lack of studies of clastic sedimentation from either rock walls or caves and rockshelters in geographically restricted sites precludes evaluation of the role of microclimate versus regional climate in influencing the texture or morphology of sedimentary particles.

Laville et al. (1980) attribute what they term "primary frost weathering" to the volumetric expansion of pore water upon freezing. Primary frost weathering is distinguished from secondary frost weathering, the latter occurring after the clast has become part of the shelter fill.

The variables (as exemplified by Laville et al. 1980, but derived ultimately from Lais 1941 and Bonifay 1956, 1962) believed to be important in the primary frost weathering process, leading to dislodgement of clasts from shelter walls and ceilings are: 1) attributes of the parent rock, 2) moisture levels attained, and 3) the rate, intensity, and duration of freezing conditions. The more rigorous the climate (i.e. rapid temperature drop, low temperature, for a lengthy period of time), the greater the production of clasts through primary frost weathering. The rate of primary frost weathering and hence climate can be determined by characteristics of the sedimentary deposit: "...the degree of cryoclastism to be attributed to any *abri* sediment is at least roughly measurable in terms of its texture, that is, the average size of its limestone *éboulis* fragments and the extent to which they dominate it volumetrically...(Laville et al. 1980:53). The interpretation of the climate of formation can be further refined by examining the texture and morphology of the sediment in more detail. In their opinion, for example, based on laboratory evidence of physical weathering rates under various climatic conditions (e.g. Lautridou and Ozouf 1982), freezing of considerable amplitude but with few cycles will produce very coarse clasts with an underrepresentation of the fine fraction. On the other hand, lower amplitude freezing,

with a greater number of cycles across the freezing point will result in the exfoliation of individual sand and silt grains, producing a greater percentage of fine fraction materials.

Farrand's (1975) study of the Abri Pataud suggested that a greater number of freeze-thaw cycles with a greater intensity of freezing and saturation of the host rock will produce smaller clasts but an overall greater number of clasts >1 cm:

"Thus, the size and abundance of frost debris is a complicated function of *time* (number of freeze-thaw cycles), *temperature* (intensity frost) and *moisture* (degree of saturation), with the overall result that, for any given limestone, the size of the resulting debris is inversely proportional and the quantity of debris is directly proportional to each of these factors" (Farrand 1975: 53).

Farrand (1975) also distinguishes between "frost spalls", relatively small chips of rock removed from a solid rock surface by growth of interstitial ice and "frost blocks", blocks of rocks detached by growth of ice in a natural crack system of rock.

More recently Farrand (1985) has backed down from such strict cause and effect statements as those discussed above. When the principles of cave sedimentology were first stated, Lais (1941) and others based their methods on the assumption that freezing and thawing of water in pore spaces was the most important factor in rock disaggregation under cold climate. As discussed below, both the mechanism and the expected products of freezing and thawing are currently poorly understood.

Open System Approach

The "open system" approach to the reconstruction of the climate from sediment accumulation in rockshelters seeks to demonstrate the degree to which exterior geomorphic agents introduce measurable quantities of clastic sediment into caves and rockshelters. If autochthonous sediments can be separated from introduced sediment particles variation in the quantity and quality of introduced sediment can be used to infer the climate prevailing during the formation of individual strata. This reconstruction is based upon linking climate change to vegetative change and the importance of vegetation in controlling slope stability and hence, the availability of material for introduction into the rockshelter.

Lais (1941) and others discussed the introduction of allochthonous sediments into Paleolithic caves in Germany. He discussed the climatic implications of aeolian dust blown into caves and sediment washed in through ceiling fissures. Farrand (1975) mineralogically separated windblown sand from the fine fraction of cave sediments in the Abri Pataud. Butzer (1981) separated allochthonous from autochthonous sediments in the fine fraction of sediments in caves located in northern Spain. The textural parameters of allochthonous sediments were then used to reconstruct the climate of formation of strata in these caves, permitting Butzer to correlate chronologically the strata in the caves to isotopically defined marine stages.

To the extent that the tenuous assumptions concerning the link between climate-vegetation and allochthonous cave sediments are valid, it is possible to create a climatostratigraphic framework for individual sites (presumably with all climates represented) and to temporally correlate sites within a region by reference to a regional and, ultimately, a global climatostratigraphic framework.

The advantages of this method are that it is less destructive of a site in so far as significantly smaller sample sizes are necessary (Butzer 1981), a significant advantage when working at many archaeological sites where destruction through sampling is often viewed negatively. The method also promises the potential for application outside regions or periods of time marked by significant climate change between very cold and more temperate climates. Ahler (1976) and McMillan and Klippel (1981) used a similar approach in caves where the bulk of the sediment was considered to be allochthonous, to detect relatively minor (by Pleistocene/Holocene standards) changes in mid-Holocene climate on the prairie-forest boundary in the midwestern United States.

Although this approach offers an important geomorphic perspective, it is virtually certain that there is no simple relationship between climate and vegetative change on the one hand, and the quantity and mineral composition of sediment introduction within a rockshelter. In addition, palynological studies the existence of an appreciable lag time between changes in vegetation and the climate responsible for the change (Birks 1980). Added to this, there should exist an additional lag between vegetative change and the introduction within the rockshelter of sediment of changed character resulting from the episodic transport of sediment by unchanneled flow (Statham 1977).

There also exists a tenuous connection between climate, vegetation and slope processes. Although it is clear that vegetation is an overriding factor controlling rates of erosion on slopes by overland flow and rainsplash, the relationship of vegetative change to climate is less clear cut. Reduction in vegetative cover could just as easily be due to overgrazing, burning or other non-climatic factors. Also, unless the nature of the vegetative change is understood *a priori*, the interpretation becomes even more tenuous. The substitution of different plant taxa in response to climatic change may or may not affect slope processes. It is easy to envision a situation in which very dissimilar climates may create very similar geomorphic conditions. Not all climatic changes would therefore necessarily be recorded, thus precluding accurate correlation to other climatostratigraphic frameworks.

A further difficulty arises in separating the various processes by which fine sediment can be introduced into cave or rockshelter deposits. Though it may be possible to separate allochthonous elements in a sedimentary accumulation, exact determination of their origin, and hence the link to climate, is a difficult, often unanswered question.

SUMMARY

A number of problems need to be resolved before climatic sequences erected from cave sedimentological methods will be of general utility. First and foremost, experimental and empirical evidence must be marshalled to answer the questions linking climate to sediment production within rockshelters. For instance, how great a climate change is necessary to produce a measurable variation in sedimentary units? North American workers, operating over a short time span and using the open system approach have identified the relatively minor climatic variations within the Holocene (Ahler 1976, McMillan and Klippel 1981). Given that the assumptions behind the closed system approach are valid, how small a climatic change is necessary before it can be observed in autochthonous sediments?

Notably, the American Commission on Stratigraphic Nomenclature (ACSN 1983) has moved away from the notion of climatostratigraphic units, originally defined in the code (ACSN 1961), determining them to be too ambiguous and difficult to determine upper and lower boundaries. The reasons for this involve the difficulty in accurately ascribing climatic parameters to the genesis of particular sedimentary units.

PHYSICAL WEATHERING LITERATURE

Most introductory geology textbooks still cite the volumetric expansion of ice on freezing as the paramount factor in rock disaggregation in cold climates (for one of the few alternative views see Grawe, 1936). In recent years, this view has come under increasing scrutiny through experimental and field studies (e.g. Fahey and Dagasse 1984, Hudec 1973, Lautridou and Ozouf 1982). At the present time it is clear only that: 1) mechanisms other than the volumetric expansion of water on freezing are capable of disaggregating rock under laboratory modelling of natural conditions and in field studies; 2) several of these mechanisms operate in the absence of temperature fluctuations through 0° C; 3) different lithologies respond individualistically to input conditions (e.g. temperature, moisture, etc.).

Field and laboratory studies have made it clear that the physical weathering of rock under freezing conditions can occur in several ways. Lautridou (1988) makes an important distinction between frost scaling, splitting and wedging. Frost scaling is defined as the production of thin slabs of rock by the formation of thin ice lenses, parallel to the outer rock surface. Frost splitting is the disaggregation of previously uncracked rock, sometimes also termed "bursting". Frost wedging is the familiar example of ice forming in pre-existing weaknesses such as joints, on a macro scale. Two further terms are commonly employed in describing the mechanical disaggregation of solid rock by freezing and thawing of water; micro- and macrogelivation (Tricart and Cailleux 1972). Microgelivation refers to the expansion of water on freezing in micro pores in the rock and would be most closely allied with frost splitting. Macrogelivation refers to the expansion on freezing of water in macroscopic joints, bedding surfaces, or other rock discontinuities.

These distinctions are important in that the two processes result in the production of two different and theoretically important categories of material. Microgelivation produces small (<2 mm) clast sizes, a possible source for loess and other fine-grained material. Macrogelivation produces larger clast sizes, providing the source of material for blockfields and talus, or the coarse fraction in caves and rockshelters.

The proposed mechanisms for rock disaggregation and references to their documentation are listed in Table 2. In all proposed mechanisms, the role of moisture is paramount, and thus disaggregation is not simply a function of temperature as assumed by classical cave sedimentologists (with this in mind, it is difficult to envisage how an *éboulis sec* could be produced under cold and dry conditions. Perhaps, as Farrand (1975) has suggested, it is more realistically related to roof collapse). Additionally, the characteristics of the rock under investigation (particularly porosity, cf. Lautridou 1988) strongly influence and/or determine the nature of disaggregation and whether or not it will occur at all.

That the nature of temperature changes cannot be directly interpreted from the geological record is underlined by the current disagreement among experimentalists regarding the conditions necessary for freeze-thaw disaggregation: 1) moisture, both in terms of total content and its state within the rock, 2) freezing rate, 3) amplitude of freezing, and 4) frequency of cycles. Thus far agreement has not been reached on the relative importance of any or all of these conditions.

Laboratory Studies

Tricart (1976) began the process of laboratory modelling of freeze-thaw weathering of rocks under natural conditions. In his pioneering research, he led the way in pointing to abundant moisture as a necessary precondition to freeze-thaw weathering, and outlined the various freeze-thaw variables that might influence the rate of rock breakdown (McGreevy 1982); rock type and structure, moisture content, freezing intensity, amplitude of freeze thaw cycles, and frequency of freeze thaw cycles. Since this initial work, a great deal of research has attempted to isolate the efficacy of the variables cited above in promoting rock disaggregation. However, only limited agreement has been reached and several alternative mechanisms of rock disaggregation have been proposed.

Lautridou and Ozouf (1982) reviewed the results of some 15 years of laboratory research at the Centre de Géomorphologie in France. Although they were unable to specify the mechanism of frost shattering other than indicating that water expansion on freezing combined with hydraulic pressures under freezing, these authors suggest that it may be possible to reconstruct the climate of formation that produced a particular deposit of mechanically weathered rock. They also feel that particular morphological types are produced under certain weathering conditions.

Hudec and others (Dunn and Hudec 1966; Hudec 1973) varied temperature and moisture content independently (in contrast to other earlier experimentalists). These

studies pointed to the adsorption of water on clay mineral surfaces in rocks as a potential source of stresses capable of disaggregating rock under conditions above 0° C.

Walder and Hallet (1985, 1986) have provided theoretical evidence to suggest that the disaggregation of solid rock in response to freezing temperatures is more a phenomenon of "ice-lensing", as suggested for soils in permafrost regimes (Taber 1929). In this model, saturated conditions are not a prerequisite for stress development, as water is continually drawn into the freezing front by thermal-chemical gradients.

At present, there is little agreement among laboratory studies. As McGreevy and Whalley (1985) and others have pointed out, laboratory modelling of natural conditions, although allowing control of variables, may not provide accurate analogs for field conditions. Particularly, laboratory studies generally saturate specimens, conditions that would occur only in unusual sites under natural conditions. Additionally, scale problems preclude replication of macroglaciation in laboratory conditions (Lautridou and Ozouf 1982).

Field Studies

Field observation of rock disaggregation, or the documentation of laboratory specified conditions in the field have been somewhat sparse. Thorn (1978, 1979, 1980) and Thorn and Hall (1980), have independently monitored temperature fluctuations in alpine environments. Their research indicates that 1) air temperature is a grossly inadequate indicator of rock temperature, and 2) conditions matching laboratory derived criteria for freeze-thaw disaggregation are rarely achieved in the field (temperature fluctuations in conjunction with ample moisture).

Douglas (1980) monitored temperature, moisture and rockfall production in a basalt cliff. His results were not entirely conclusive, but indicated only a weak correlation between rockfall magnitude and frequency, and temperature. In his study, tectonic stress release appeared to be more critical for production of rockfall.

Coutard and Francou (1989) monitored rock temperature fluctuations in the French Alps over a one year period. Their research indicated the significance of microclimatic variation due to aspect as well as altitude in producing significant variation in freeze-thaw frequency and intensity. Their study did not, however, determine the characteristics of the material produced by freezing and thawing of moisture within the rocks.

Matsuoka (1990) performed field observations over a two year period of temperature and moisture variation on rock surfaces in the Japanese Alps. His study also involved an evaluation of the total amount of weathering on these rock surfaces. The results of this study were that freeze thaw frequency, degree of saturation, and tensile strength of the rock are the most important variables. He was also able to identify more limited disaggregation during the non-winter months, apparently by elevated moisture following intense rainstorms.

For areas characterized by low humidity and rare freezing temperatures various experimental and field investigations have focused on the efficacy of salt crystallization and/or hydration in the granular disintegration of rock (e.g. Cooke and Smalley 1968, Fahey 1986). These processes may operate in conjunction with freezing temperatures to accelerate rock breakdown (Williams and Robinson 1981, Trenhaile and Mercan 1984, Trenhaile and Rudakas 1981), or operate in desert conditions (Smith and McGreevy 1983, McGreevy and Smith 1984, Chapman 1980, Evans 1970).

SUMMARY

The important implications of the research reviewed above is that 1) the degree to which freeze-thaw and/or hydration weathering are important components in the disintegration of solid rock under cold climates is not yet fully understood, and 2) the conditions necessary to promote either of the two processes have yet to be identified.

It is certain that freeze-thaw weathering is an important process in what the French call macrogelivation, or the production of relatively coarse fragments by the expansion of water upon freezing in previously existing joints or cracks in bedrock. What is not well understood, however, are the conditions necessary for this to occur in nature. The studies by Thorn and Hall (1980) suggest that appropriate conditions are often difficult to find in the field as abundant moisture in conjunction with depressed temperatures suitable for freezing are not commonly combined. The breakup of rocks by microgelivation is poorly understood and specific generalizations regarding this process are currently not possible.

At this point, it would seem impossible to quantitatively reconstruct past regional climatic conditions from an assemblage of weathered rock fragments under even ideal conditions. The research reviewed above suggests that one must first specify the original porosity of the host rock, define the source of moisture and its mode of entry into the rock, and finally, establish the timing and distribution of fluctuations over the 0° isotherm.

In working with ancient cave and rockshelter sedimentary fills, it is impossible to determine, with any degree of confidence, the original porosity of the host rock as only minimal values may be ascertained. The source of moisture is even more difficult to relate to regional climate. As opposed to surface sites or exposed rock walls, the ceiling and walls of caves receive moisture primarily by infiltration through the overlying bedrock. The amount of moisture reaching the cave may vary significantly depending upon the presence or absence of a vegetative cover above the cave or fissures that may close by clogging through time. Additionally, the orientation of the cave mouth with respect to paleowind directions may be significant in terms of trapping snowdrifts that may provide an important source of moisture.

Chapter 3

Research Design

INTRODUCTION

As indicated in the previous chapter, there is little experimental verification, at least in a straightforward sense, for the interpretive models linking exterior macroclimate to sediment production in rockshelters. The design of this research project is to examine modern and late Quaternary sediment fills in rockshelters with the aim of providing empirical evidence concerning the postulated relationship between climate and sediment formation. The disadvantages for this avenue of research are obvious and revolve primarily around the lack of really accurate control of external variables on climate, except in a very gross sense. The advantages, however, given an already adequate, if as yet inconclusive experimental referent, have to do with the scale factor (both in terms of size and time), and the possibility of documenting other significant processes by which sediment is introduced into rockshelters. Additionally, while others have measured the input variables for the mechanical weathering equation with some degree of accuracy (i.e. moisture, temperature), these studies do not examine the output, in terms of texture and morphology of the clasts produced.

CLIMATIC TRANSECTS

A great difficulty in European cave sedimentology has been the lack of suitable analogues for climatic conditions during the Pleistocene. The sites lie today mostly within mild, temperate climatic regimes, but during portions of the Pleistocene the sites formed under much cooler conditions. Bearing in mind Colcutt's (1979) admonition that, with respect to the latitudinal requirement, no true analogues for low latitude glacial climates exist today, it was decided to examine rockshelter fills along both latitudinal and altitudinal transects in montane western North America. Though not directly analogous, the climates in the areas selected certainly span the range of temperature, if not moisture, conditions experienced at low altitude areas in Europe during the Pleistocene. The altitudinal transect offers the opportunity to examine shelters receiving sediments under varied microclimates and in varied geomorphic situations, but within a relatively restricted area. Site study areas examined in this dissertation are plotted on Figure 2. Table 3 provides additional information concerning the location and characteristics of the sites to be discussed.

The original plan was to examine a large number of modern surface sediments from sites along these climatic transects, in addition to earlier Holocene sediments. However, a great deal of quantitative information from these investigations was lost and therefore only qualitative observations remain for all except the surface sedimentary units of the excavated rockshelters. However, for those surface sediments sampled, a simple comparison along the transects, accounting for differences in local lithologies should provide valuable data concerning the relationship between climate and the texture and morphology of the sediment produced. The obvious advantage in using modern surface sediments, if in fact they can be demonstrated to be modern, lies in the ease of evaluating geomorphic criteria for introduction of sediment from exterior sources; a major problem when dealing with essentially fossil geomorphic systems in Pleistocene sites no longer receiving sediment.

In addition, where possible, it was decided to examine late Quaternary rockshelter fills in conjunction with ongoing archaeological excavations. For these sediments it is more difficult to infer the background climatic and geomorphic conditions. However, for western North America more detail exists concerning late Quaternary climatic change to compare lithostratigraphic units in excavated rockshelters with local climatic sequences.

Clearly, if the basic tenets of the classical cave sedimentological school are accurate, the major climatic periods defined for western North America should be reflected in the sediment accumulations, unless it can be shown that regional climatic change is masked by local, microenvironmental conditions.

A series of hypotheses can be formulated to test against the sedimentary record of late Quaternary sediment fills sampled for this study.

Assumption

Regional climate is the dominant variable determining the character of sediment produced in rockshelters and entrance facies of caves and will therefore:

Hypotheses

1. produce a continuum of sedimentary products along the altitudinal and latitudinal and climatic transect, more coarse toward the higher latitude and altitude end.
2. be reflected in late Quaternary sections as a sequence of lithostratigraphic units mirroring the climatic zones defined for the local area.

FIELD METHODOLOGY

Sites for study were selected primarily on the basis of prior or on-going excavation by archaeological or paleontological teams. Surface sites were examined where available and where prior disturbance by humans was not recognized.

Upon visual inspection, exposed sections were subdivided into stratigraphic units where textural, mineralogical, or other physical properties allowed distinction. These units have the status of informal lithostratigraphic units (ACSN 1983). In every instance, the original purpose of stratigraphic subdivision was to provide a sedimentary context in which to place excavated materials, such as archaeological and paleontological remains. Unit definition was made on as small a scale as possible, thus some units are simple, thin (ca. 1 cm) lenses. In other instances, due to lithologic homogeneity, the entire exposure is included within a single lithostratigraphic unit.

To avoid confusion, naming of lithostratigraphic units followed archaeologic unit designations where possible. In several instances, unit designations for a section were either simplified, or finer distinctions were made where appropriate. Where numbered, or lettered, labelling proceeds from top to bottom. Although this method of unit designation is contrary to standard geologic thought, it is necessary when units must be named during on-going excavations, and there is no way to know beforehand the number of units that will ultimately be uncovered.

Samples were collected in vertical sample columns from the bottom up in portions of the section that were observed to be typical of the sediment accumulation as a whole. At least one sediment sample was taken from each defined stratigraphic unit, with several collected from relatively thick units (thick units were sampled in 15 cm thick vertical columns). Surface sites were sampled along a transect from the mouth to the rear of the shelter so as to sample the range of variability produced as a result of cave microenvironmental influences. For excavated sites, sample columns were taken where possible with the above strategy in mind, but in practice, sample columns were taken wherever possible (as excavations were ongoing in many cases and the archaeologist on several occasions objected to disturbing a cleaned section).

Bulk sediment samples of approximately 20 kg were taken when the sample contained quantities of clasts greater than 1 cm in size. Substantially smaller samples were collected from dominantly fine-grained sediments. Where possible, these samples were dried, weighed, and the bulk of the fine fraction discarded in the field following the procedure

suggested by Farrand (1975). Where this procedure was impractical, bulk samples were bagged and taken to the University of Alberta Geoarchaeology Laboratory.

A great deal of field time was also spent studying the local geomorphic situation to evaluate the possibility of either outside sediment introduction and/or removal and redistribution of sediment from within the cave.

LAB METHODS

The first procedure in sample analysis was separation of the bulk sample into three size fractions, each fraction to be subjected to somewhat different analyses. Following the terminology outlined, by Farrand (1975), size fractions were labelled as: the **coarse** or **A-fraction** consisting of clasts >100 mm; the **medium** or **B-fraction** consisting of clasts >2 mm <100 ; and the **fine** or **C-fraction** consisting of clasts <2 mm. The A-fraction consists of clast sizes that are in all probability autochthonous to a particular shelter, except where high energy processes capable of moving gravel-sized clasts were available. The C-fraction will contain possible allochthonous elements which can be detected mineralogically or geochemically. The B-fraction is separated from the A-fraction as these clasts are too small to reliably determine clast maximum dimensions or to make morphological observations.

Following separation, all fractions were subjected to textural analysis. The long-axes of coarse fraction clasts were measured. Medium fraction clasts were sifted for 20 minutes on a stack of five sieves (8 mm; 6.3 mm; 4 mm; 2.8 mm; 2.3 mm; 2 mm). The fine fraction was analyzed by the hydrometer method (following the procedure outlined in Catto and Proudfoot 1983). Pretreatment for removal of organic matter, with NaOCl where there existed substantial carbonates or with H_2O_2 where carbonates were not prominent, was carried out following the method outlined by Lavkulich and Wiens (1970). The sand component was further sieved for 20 minutes through a stack of 9 sieves (1.41 mm, 1.00 mm, 0.71 mm, 0.50 mm, 0.35 mm, 0.25 mm, 0.177 mm, 0.125 mm, 0.088 mm).

The gravel fraction was further analyzed with respect to roundness, following the procedure outlined by Farrand (1975) for cave sediments. In this method, clasts are divided into four classes; angular (all edges angular), subangular (a greater percentage of angular than rounded edges), subrounded (a greater percentage of rounded than angular edges) and rounded (all edges rounded). For purposes of comparing roundness of clasts between sites, the Roundness Index of Madeyska (1982) was employed:

$$RI = A * 0 + SA * 1 + SR * 2 + R * 3$$

where

A = angular
SA = subangular
SR = subrounded
R = rounded

The gravel fraction was further analyzed for secondary concretionary coatings on one or more surfaces of the clast. As suggested by various workers (Laville 1975, Farrand 1975) a solid concretionary coating ("P" concretions of Laville et al. 1980) indicates secondary precipitation of calcite while the clasts was still lodged with the shelter wall or ceiling. It is believed that the presence of these concretions indicates relatively warm and humid conditions that would promote dissolution of calcite and precipitation in fissures of the cave walls and ceiling.

Further analysis of the fine fraction consisted of color, geochemical, and mineralogical analyses. Color was determined on air dried samples using the Munsell Color Chart. Sample pH was determined on a slurry of sediment using a Cornell 1100 pH meter. The percentage of calcite and dolomite was determined using the Chittick method (Dreimanis

1968). Organic matter content was determined by loss on ignition following the procedure of Stein (1984).

Grain size measures were calculated after the methods outlined in Folk (1980). Sorting is calculated by the inclusive graphic standard deviation method (σ_1) with the value presented in ϕ (phi) units. Skewness (Sk_1) was calculated following the inclusive graphic skewness method. Kurtosis (K_G) was calculated following the graphic kurtosis method. Graphic mean (M_z) and median size (M_d) of the fine fraction was calculated in phi units following methods suggested by Folk (1980). Millimeter values for mean and median for A-fraction clasts were calculated following methods outlined in Blatt et al. (1980). Formulas for these methods are presented in Table 4.

PRESENTATION OF DATA

Certain sites are presented in greater detail than others, because at these sites I was the sole geologist responsible for analysis of the sediments. For other sites (e.g. Northern Yukon) my role was strictly limited to a largely ahistoric evaluation of the character of sediments and not with the history of their development. For this reason, a detailed sedimentary history will be reconstructed for some sites (particularly the Pryor Mountains), while for others the history will be treated only cursorily.

CAVE AND ROCKSHELTER FACIES MODEL

When attempting to reconstruct the climate under which sediments within a cave were deposited it is imperative to understand the myriad means by which sediments can be introduced to the cave environment. In this section, I will outline the possible methods by which sediments may become introduced to a rockshelter environment and the variety of ways in which sediments undergo diagenesis following deposition. This discussion is keyed to Figure 3, modified from an original figure presented by Schmid (1969).

The cave or rockshelter environment is divided into a Sill, extending beyond the **Entrance** (beneath and in front of the cave brow) and **Front** and **Inner parts**. The entrance is traditionally the most significant portion of a shelter for climatic analysis (Bonifay 1956, Lais 1941); it is here that the bulk of human occupation occurs, and it is here that the exterior climate has the greatest impact. In front of the drip line, stratigraphic subdivision is often obscured by colluvium from above and the action of runoff. Deep within the interior of the cave, the microclimate is moderated to a greater extent (Farrand 1985).

Deposition of sediments within a cave can take place through a series of processes, as outlined in Figure 3. As discussed earlier, those employing an open system approach would focus most heavily on Processes 1 and 2, while the closed system approach relies largely on Process 3 and only secondarily on Process 1 (primarily for interpreting post-depositional alteration of the primary sediments such as the unconformities indicative of interglacial or interstadial climates recognized by Laville et al. 1980).

Process 1: washing in from above the shelter.

Most caves and rockshelters open to the outside along a hillslope having an angle ranging from vertical cliffs to more gentle slopes. Slope steepness is an important factor influencing the amount of runoff into the cave, and the nature of mass movements potentially introducing sediment into the cave. The position of the shelter with respect to position on the slope is also crucial to a sedimentological evaluation. Caves situated near the heads of slopes would be least likely to receive sediment and runoff from above. Caves at the toes of slopes or on more gentle slopes would more likely receive sediment and runoff. End-members of these potential geomorphic positions are illustrated in Figure 4.

Introduction of sediment from sources above the cave can only occur by movement of material along the hillslope above the cave and then into the shelter either from: 1), gravity fall from the cave brow or, 2) along the slopes adjacent to the cave mouth or by, 3) movement of material through cracks in the rock forming the walls and ceiling.

Mechanism 1 is responsible for the lip mound deposits commonly seen in entrance facies. Mechanism 2 may result in build-up of small alluvial cones at the juncture between the hillslope and the shelter floor. Mechanism 3 has been little recognized in the sedimentological literature but proved significant in several of the sites reported in this study.

In any case, the entrance area should receive considerable sediment of a diverse nature and also be greatly affected by rain-splash erosion as the brow will serve to focus all the upslope runoff along a relatively narrow area. It should then, be possible to detect these entrance facies sedimentologically in cases where the modern drip line has retreated significantly from ancient positions.

Sediment movement towards the cave interior beyond the cave brow should be accomplished primarily by a combination of rainsplash and unchanneled overland flow, possibly including minor channelization in the form of rills. It seems unlikely that very much sediment can be moved very far towards the interior by this mechanism. On steeper slopes outside the cave, various mass movements from the debris accumulation beneath the cave brow would result.

Movement of fine sediment particles through the ceiling rock obviously is dependent upon an integrated joint system extending from the land surface down to the ceiling of the cave. Recognition of allochthonous sediment is generally only possible where overlying strata are sufficiently distinct lithologically. This phenomenon has been observed occurring in modern times during the course of this study, as well as in ancient sediments in other areas (e.g. Madeyska 1982).

Process 2: Introduction of sediment through aeolian and biologic agencies

Aeolian introduction of material is always a possibility in caves and rockshelters. Farrand (1975) was able to detect by mineralogical means the introduction of predominantly sand-sized clasts blowing in from an adjacent stream. It may prove difficult in other instances to detect aeolian processes where the surrounding sediments serving as the source sediment are identical to those within the shelter. However, the detection of an aeolian fraction is significant for an understanding of the local vegetation and geomorphology.

Depending upon the intensity of the utilization of the rockshelter by animals (including humans), biological agencies can profoundly influence the character of a primary sediment. Where rodents or other mammals nest or den in the shelter the potential for "tracking" in clastic sediment on paws, hooves, or fur is a real possibility although it is unlikely this sediment would be a dominant fraction. To the extent that animals soil their own nest, the accumulation of organic sediment in the form of dung and nesting materials may add significantly to the accumulating deposit. Contained within this sediment should be a small, but detectable fraction of mineral sediment. The latter would serve primarily as a tracer for allochthonous sediment, or perhaps be confused with fine-grained windblown sediment. The organic sediment, if not quickly decomposed, could alter the texture and certainly the color of the deposits, regardless of other changes in textural parameters. Finally, certain birds contain small, gravel-sized clasts within their gullets which, upon the death of the bird, may become introduced into the rockshelter environment in small quantities.

Process 3: Coarse clastic gravity-fall debris from ceilings and walls

Coarse clastic debris from the ceilings and walls of caves, particularly near the entrance, often constitutes a major portion of the sediment in caves. As discussed in Chapter 2, these sediments become detached from the ceilings and walls by as yet poorly

understood processes that may include freeze-thaw weathering as well as other forms of clast removal both above and below 0° C (e.g. hydration and ice lensing), or mechanisms that have little to do with temperature (e.g. earthquakes, crystal growth, or rock bursts). Although the mechanisms of clast disaggregation are still poorly understood, it is this property of variation in coarse clastic content of strata that is most commonly employed to estimate the climate of formation, following the original suggestion by Bonifay (1956, 1962).

The morphology of clasts, and the presence of concretionary coatings on gravity-fall debris are also employed to infer aspects of the regional climate. Subangular and subrounded clasts may have undergone rounding while still attached to the wall rock (Farrand 1975). Rounded clasts achieve their morphology after deposition and are discussed below in the section on diagenesis. Hard, travertine-like, secondary carbonate concretions (concrétions P of Bonifay 1956) are presumably formed on clasts still attached to the cave wall.

Dissolution of carbonates and reprecipitation is not strictly phenomenon of warm, humid climates as suggested by Bonifay (1956) and Laville et al. (1980). A variety of karst solutional features have been recognized in high alpine areas (White 1979, Campbell 1979, Maslyn and Davis 1979). Though Corbel's (1959) idea that cold, arctic or alpine waters should be more aggressive with respect to carbonate solution has not been supported (Bloom 1978), studies in cold climates suggest it is an active process. Much of the lack of karst surfaces may have to do more with rapid rates of mechanical weathering rather than a lack of karst processes.

Similarly, secondary carbonate precipitation has been identified in subglacial situations (Hallet 1979) and in cold, dry subarctic conditions (Forman and Miller 1984, Dijkmans and Koster 1986). Thus, features of carbonate solution and precipitation are not readily interpretable in terms of regional climate.

Diagenetic Processes

After sediments in caves and rockshelters have been deposited and protected from erosion processes at the surface, they may still undergo significant mechanical or chemical post-depositional alteration. Depending upon the depth to which these processes operate, the sediments may undergo progressive alteration. Diagenetic weathering rates are unlikely to be linear with respect to time though it is impossible for the sedimentologist to determine this *post fact*.

Alternatively, some diagenetic processes may affect only a particular portion of the sediment accumulation (e.g. pedogenesis). In either case, post-depositional alteration of sedimentary accumulations may alter them so as to make them more susceptible to additional weathering processes (Forman and Miller 1984). For instance, increased porosity brought about by corrosion may increase the viability of microgelivation processes.

Laville et al. (1980) and Farrand (1975) describe "soils" formed within rockshelters. In the Perigord region, Laville et al. (1980) recognize these pedogenic horizons by the secondary enrichment in CaCO_3 and clay stratigraphically beneath unconformities. Two conditions are necessary in order to invite eluviation and illuviation of secondary clays. First there must be clay present and sufficient water to wash it through a profile. Second, pore spaces, significantly larger than the clast-size in question must be present to act as conduits. The presence of abundant pore spaces implies a soil structure unexpected in caves and rockshelters. Clays must also be dispersed so that they can remain in suspension rather than flocculate. In CaCO_3 -rich soils as expected in a limestone rockshelter, clays have a thin ion layer and will tend towards flocculation, thus inhibiting translocation.

All the above suggest, on theoretical grounds, that clay translocation is not likely to be a rapid process in relatively dry caves and rockshelters. A thin-section study by Goldberg (1979), concerning two caves in which clay translocation was identified on the basis of

granulometric evidence, demonstrated a lack of oriented clays and clay films, suggesting that enrichment in clay was not due to pedogenic causes.

Laville et al. (1980) indicate that the soil horizons are characteristically truncated by erosion through gullying by surface waters, a phenomenon they believe signifies the onset of glacial/stadial conditions. There would seem to be no reason to expect "gullying" to precede a change to a colder climate, since if the geomorphic position of the cave was such that surface water flows were a possibility, erosion and gullying would seem to be equally likely during any period in which sufficient precipitation existed to generate overland flows.

Certainly pedogenic processes occur, at least in the entrance facies of caves and rockshelters. It is unlikely, however, that thick, organic rich A horizons would be expected to develop where a sufficient build-up of vegetation and, ultimately, organic matter does not exist. This would be the case where humans or other mammals are occupying the shelter in a relatively intense manner (in this case a thick organic rich stratum may develop, but this would be significantly different from a pedogenic A horizon). However, other pedogenic processes, including deposition of secondary minerals such as carbonates and weathering of various aluminum and iron oxides and clay minerals, would take place depending upon the intensity of conditions promoting those processes and reactions. It is interesting to speculate that where Laville et al. (1980) recognized unconformities by the presumed removal of pedogenic A horizons, these horizons may never have existed at all. Rather, as reported for the Abri Pataud (Farrand 1975), the soils may consist merely of a weathered horizon, visually detected by reddish colors, accompanied by enrichment in secondary CaCO_3 .

Time-dependent decay of organic matter may occur down the section in the absence of low temperatures or saturated conditions. The majority of sites discussed in this study are very rich in organic matter resulting both from the use of the sites as nests, and from plant growth. The decay of large quantities of organic matter may further enhance diagenetic processes through alteration of Eh, pH conditions.

Progressive enrichment of lower strata in secondary carbonates is commonly observed in caves and rockshelters of the temperate zone. Several authors (e.g. Madeyska 1982) cite this phenomenon as evidence for warm, moist conditions, with solution of carbonates in upper strata and their precipitation lower in the section. That carbonate dissolution and precipitation at depth are not restricted to warm, humid climates is demonstrated by Dijkmans and Koster (1986), who present evidence for pedogenic carbonates in subarctic conditions in Alaska.

Alterations of clasts, particularly limestone clasts, may occur through corrosion which may result in increased rounding of clasts, formation of corrosion hollows, and increased clast porosity. These phenomena are most commonly attributed to weathering under warm, humid climates (e.g. Madeyska 1982, Laville et al. 1980, Schmid 1969). However, there is no reason such diagenetic alteration could not occur under relatively cold climates where sufficient soil CO_2 or acids produced from biological decay exist (Forman and Miller 1984, Dijkmans and Koster 1986).

The presence of large quantities of organic matter in cave sediments may substantially alter the diagenetic environment, masking the influence of the exterior, regional climate. Elevated levels of organic matter content significantly increase the porosity of sediments, particularly those with substantial silt and clay, by promoting aggregation into granular sediment particles (Bohn et al. 1985). Soil organic matter is capable of absorbing 20 times its weight in water simply from the atmosphere, and is capable of absorbing and retaining high levels of moisture from rainfall or snowmelt (Bohn et al. 1985, Stevenson 1982). Excess moisture retained by organic matter, or promotion of water absorption by increased porosity, would both affect the degree of corrosion exhibited by clasts.

Climatic Interpretation

The reconstruction of paleoclimates has been perhaps the major thrust in Quaternary research over the last 20 years. Lacking instrumental data on past climates for all but the most recent decades, Quaternary scientists have utilized an enormous variety of proxy climate indicators from variations in the ratio of the stable isotopes of oxygen in carbonates or ice to changes in the rate of influx or percentages of pollen from plant taxa in lacustrine sediments. Many proxy climate indicators may respond to particular variables of regional climate, such as Holocene cirque glacier fluctuations. Other indicators, including changed vegetation patterns inferred from palynological study, may reflect changes in regional climate, filtered through the different rates of dispersal and migration of the taxa. On the other hand, the edaphic, or local microenvironmental factors may outweigh the influence of fluctuations in regional climatic parameters. If the influence of regional versus microclimatic factors can be distinguished for particular proxy climate indicators it is often difficult to separate the role of the climatic variables of moisture versus temperature. Many sets of data, for instance changes in glacial mass balances, require that changes in one variable, e.g. precipitation, are understood, or at least assumed, before changes in the dependent variable can be assessed.

The recovery of paleoclimatic data from cave and rockshelter sediments is complicated by all of the factors outlined above. As discussed by Farrand (1975) and indicated by the review of physical weathering literature, it is difficult to separate the influence of changed paleo-moisture levels from changes in the magnitude and frequency of freeze thaw events when interpreting variations in the texture and morphology of coarse clastic cave sediments.

A further difficulty arises in distinguishing between changes in the cave paleo-microclimate and regional paleoclimatic change. Caves were originally believed to be excellent indicators of regional paleoclimate because of the averaging of temperature changes within caves. However, in the entrance of a cave or rockshelter, depending upon the aspect of the site, the ceiling and wall rock may suffer relatively rapid diurnal and seasonal temperature change.

The levels of moisture attained within the cave environment are more sensitive to microclimatic factors. Regardless of changing paleo-precipitation values, unless the moisture levels with the cave environment respond in similar fashion, changed patterns of sedimentation or diagenesis would not be expected. For this reason, evidence for increased moisture levels affecting either the walls and ceiling of the shelter, or the sedimentary deposits, must be evaluated in terms of effective moisture; i.e. moisture within the cave during the appropriate season or in the right place (e.g. early spring meltwater accumulation in rockwall joints) to accomplish the particular process, for instance diagenetic rounding of clasts, before an inference of changed regional precipitation patterns is made. As discussed above, increases in the accumulation of organic matter within a stratum could be expected to increase the effective moisture available for diagenesis of those sediments, regardless of any changes in regional precipitation.

A final issue is the modification of cave environments by human occupants. Humans may certainly introduce significant quantities of sediment or other debris within a shelter. But they are also capable of drastically altering the cave microenvironment in ways that would override changes in regional paleoclimate. The bulk of physical disaggregation of cave walls and ceilings probably occurs during the cooler months of the year, periods of time during which humans are likely to have occupied these sites. If for instance, over a 1000-year period, a band of humans periodically occupied a small rockshelter during late fall and early spring, sealing off the entrance with skins, and heating by fires, rates of production of coarse clasts should be drastically affected. Fortunately, the sites to be discussed in this study apparently witnessed only periodic, transitory occupation, so it is assumed this factor may be ruled out.

Correlation of particular biological or physical phenomena to regional paleoclimatic change is always fraught with difficulty and uncertainty, and for these reasons the American Commission on Stratigraphic Nomenclature (1983) has dropped the concept of climatostratigraphic units from the code. Correlation to changes in climate has always seemed to be a somewhat personal undertaking, with some individuals seeing pattern and correlation, and others seeing only dissimilarity and lack of correlation among events. For these reasons in the chapters to follow the climatic interpretation of changed patterns in sedimentary products is only made when other explanations are not available. An inference of changed cave microclimate as the primary factor producing variability in the sedimentary products of one stratum from those above and below it should, therefore, be made cautiously and only after other factors are ruled out. An interpretation of a changed regional paleoclimate can be made only after it can be demonstrated that the variability in sedimentary products cannot be explained by local microclimatic factors.

Chapter 4

Pryor Mountains Study Area

The Pryor Mountains consist of three relatively small, uplifted, moderately dissected, Tertiary fault blocks; Big Pryor, Red Pryor and East Pryor Mountains, separated from the neighboring Big Horn Mountains in Wyoming by the Big Horn River canyon. The study area is located approximately 50 km south of Billings, Montana (Figure 5), and extends almost to the Wyoming border. The Pryor Mountains are bounded to the west by the Beartooth and Absaroka Mountains, to the southeast by the Big Horn Mountains (of which the Pryor Mountains are simply an isolated extension) and to the south by the arid Big Horn Basin. Elevations vary from approximately 1230 m at the foot of the mountains to 2697 m on Big Pryor Mountain, the highest point in the mountain group. Major drainage occurs through the Bighorn and Clark Fork Rivers and their tributaries.

REGIONAL QUATERNARY GEOLOGY, PALEOCLIMATOLOGY, AND PALEOENVIRONMENTS

During the late Pleistocene, Laurentide and Cordilleran ice of the late Wisconsin advance extended down northern Montana (Figure 6: Mickelson et al. 1983, Waitt and Thorson 1983), although the positions of the southern boundary are uncertain (e.g. Rutter 1984, Clayton and Moran 1982, Fullerton and Colton 1986). Mountain ice complexes, or ice caps were present in the nearby Big Horn Mountains (Alden 1932, Colton et al. 1961, Salisbury and Blackwelder 1903, Porter et al. 1983, Davis 1988) and in the highlands of Yellowstone Park (Pierce 1979, Porter et al. 1983, Richmond 1986). Numerous smaller ice bodies existed in the Beartooth, Absaroka, and Crazy mountains to the west of the Pryor Mountains (Locke 1990, Porter et al. 1983). The Pryor Mountains because of their lower elevation (relative to surrounding mountain groups) were not subjected to Quaternary glaciation. For this reason, as well as the lack of suitable sites for palynological investigations, such as occur in the neighboring Big Horn Mountains (Burkhart 1976), the late Quaternary history of the Pryor Mountains is only poorly understood. The present study, and other ongoing studies of which this is a part, form the first integrated investigation into the late Quaternary history of the Pryor Mountains.

The nearest advance of late Wisconsin Laurentide ice from the Shelby, Havre, and Wood Mountain Lobes (Mickelson et al. 1983, Fullerton and Colton 1986), apparently crossed the Milk River and Missouri River about 225 km north of the Pryor Mountains. The timing of maximum extent and subsequent retreat of Laurentide ice is not well understood in this region. Mickelson et al. (1983) suggest a date between 18,000 and 20,000 yr BP for late Wisconsin till by correlation with dated alpine glacial tills in northwestern Montana. Retreat of these lobes may have occurred soon after these dates.

The Big Horn Mountains have been the subject of glacial geologic research since the beginning of this century (Salisbury and Blackwelder 1903) although, unfortunately, there still exists considerable debate concerning the timing of various glacial advances and retreats in that area. Barnhardt (1979) and Nelson (1970) have investigated portions of the eastern glaciated surface of the Big Horn Mountains. Nelson (1970) identified at least two pre-Holocene glacial advances which he referred to the Bull Lake and Pinedale Glaciations of Rocky Mountain Glacial terminology (Richmond 1965), and two or perhaps three, Holocene advances of a more restricted extent. The Pinedalian advances (stades I-IV) are believed to have terminated by at least 9000 years ago.

More recently, Drake and Esling (written communication cited in Richmond 1986b) believe that there is evidence for three glaciations. The earliest is thought to be the pre-Bull

Lake glaciation (pre-Illinoian), the second is correlated to the (Illinoian) Bull Lake Glaciation, and the third to the late Wisconsinan Pinedale glaciation (Richmond 1986b). Burkart (1976) obtained a date of $12,910 \pm 400$ BP from basal pond sediments within the area covered by the latest Wisconsinan tills.

Burkhart's (1976) pollen study in the Big Horn Mountains suggests recession of glaciers in the main valleys on the eastern slopes (due to the rainshadow effect) by 13,000 yr BP and on the more extensively glaciated western slopes by at least 10,000 yr BP. Following glacial retreat, a mixed spruce-pine woodland is seen to replace the late-glacial spruce forest occupying the lower valleys, suggesting to him warmer drier conditions than the cool moist conditions responsible for the spruce forests.

The late Wisconsinan plateau ice cap in Yellowstone Park is believed to have reached its maximum extent approximately 20,000 yr BP (Porter et al. 1983). Obsidian-hydration dating of late Pinedale recessional moraines and basal dates in ponds and bogs indicate that ice was in retreat from this region by 14,000 yr BP (Porter et al. 1983, Richmond 1986a). Readvances of late Wisconsinan ice of more limited extent (Lamar Valley moraines) may have occurred as recently as 13,000 to 11,000 yr BP (Richmond 1986a).

The Wind River Mountains, to the southwest of the Pryor Mountains also supported an ice cap during the Wisconsinan. Here no dates are available for the timing of retreat of late Wisconsinan Pinedale glaciers (Richmond 1986c). Davis (1988) summarizes evidence suggesting that the Temple Lakes advance in the Wind River range occurred between 12,000 and 11,000 yr BP.

Zwick (1980) has computed the Pleistocene snowline depression for the Absaroka and Beartooth Mountains to the south and west of the Pryor Mountains. His analysis of north-facing cirque floor elevations suggests that the modern snowline of 3110 m was depressed approximately 305 m, down to an elevation of ca. 2705 m during the Pleistocene. Zwick suggests that these data indicate a mean annual temperature during glacial times at least 1.9° C lower than the modern mean.

Locke (1990) evaluated paleo-equilibrium line altitudes (ELA) for mountain glaciers throughout western Montana (not including the Big Horn Mountains). His study indicates that the Beartooth, Madison, Gallatin and Crazy mountains suffered a depression of ELA's to approximately 2900 m, while ELA's to the west (Northern Rocky Mountains) and northwest (northern Bitterroot Mountains) were depressed to approximately 2200 and 1600 m respectively. This pattern of increasing elevation of the ELA to the east mirrors the modern distribution and suggests a regional ELA lowering of approximately 450 m. Locke (1990) suggests that winter precipitation in these highland areas may have been lower than modern values in his study area, based on an assumed 10° C summer temperature lowering.

Both Locke's (1990) and Zwick's (1980) study of Pleistocene ELA's agree in general with those calculated by Porter et al. (1983) and reproduced in Figure 6. These data indicate that the lack of Pleistocene glaciation in the Pryor Mountains resulted from their relatively low elevation with respect to Pleistocene ELA's. By reference to the studies of late Pleistocene ELA lowering to the immediate west of the Pryor Mountains, it seems likely that the upper surface of Big Pryor Mountain was several hundred meters below an elevation favoring the accumulation snow and formation of glacial ice in suitable locations. No calculation of paleo-ELA's was attempted for the neighboring Big Horn Mountains, however, Barnhardt's (1979) study of cirques on the eastern flank of these mountains shows floors above 3000 m, in line with the 3000 m paleo-ELA drawn by Porter et al. (1983) for the Big Horn Mountains (Figure 6). Barnhardt (1976) presents data on the maximum extent of glaciations in the eastern Big Horn Mountains where Pleistocene (Pinedale?) glaciers flowed more than 20 km beyond modern cirque glaciers to elevations as low as approximately 2200 m.

Péwé's (1983) map of periglacial features formed in the United States during Wisconsinan time puts the Pryor Mountains within the zone of continuous and discontinuous permafrost. Mears (1981) reported widespread ice-wedge casts in the Big

Horn Basin adjacent to the Pryor Mountains. Based on these features, and other relict frozen ground features in alpine areas of the western United States, Péwé (1983) infers a mean annual air temperature of -8°C , a drop of around 10°C from modern temperatures.

Reconstruction of the character of late Pleistocene vegetation in the Pryor Mountains and any paleoclimatic evidence that can be drawn from this study is restricted to a small number of sites, the nearest of which occur in the neighboring Big Horn Mountains (Burkhart 1976), Yellowstone Park (Baker 1983), and the Bitterroot Mountains in Idaho (Mehring et al. 1977). At bogs and lakes in these study areas, the late Pleistocene record (ca. 14,000-10,000) at all sites yielded percentages of taxa indicative of modern alpine tundra (Baker 1983). Baker suggests a treeline lowering of approximately 1200 m for the northern Rocky Mountains. Burkhart (1976) believes that the three sites he investigated, which yielded a late glacial pollen assemblage, indicate a cold, moist, late Pleistocene climate for the Big Horn Mountains.

On the basis of paleontological investigations, Chomko (1978) and Gilbert et al. (1978) reconstruct a steppe-tundra regional environment for the Big Horn Basin. Their reconstruction implies a very rigorous climate (cold and dry) for the late Glacial time period ca. 17,000-14,000 BP. Changes in the composition of small mammal assemblages after 14,000 BP and until ca. 10,000 BP, indicate a climatic amelioration and development of a grassland environment.

Following the retreat of large late Wisconsinan ice masses, the northwestern Cordillera of the United States is generally believed to have witnessed at least two further, more limited, glacial advances. Evidence for an early Holocene regional ice advance of mountain glaciers is currently under debate. Davis (1988) and Osborn and Luckman (1988) suggest that pre-Mazama ash tills and other glacial deposits, previously dated to the early Holocene, may simply represent regional late Pleistocene readvances of limited extent. The latest accepted regional ice advance, the Neoglacial (ca. 6000-5000 yr BP), has been documented from a number of sites in mountainous western Montana and Wyoming. Using lichenometry, Barnhardt (1979) distinguished at least two Neoglacial advances for cirque glaciers on the eastern flank of the Big Horn Mountains, and named an early episode the Sawtooth Lakes Advance. The late Neoglacial episode is termed the Black Tooth advance and is correlated to the Arapaho Peak advance of Benedict (1973) and the Gannet Peak Advance from the Wind River Mountains (Richmond 1965). Nelson (1970) also noted evidence for two Neoglacial advances at Clear Creek Valley on the eastern flank of the Big Horn Mountains. Undated glacial deposits attributed to the Neoglacial are believed also to be present in the Beartooth Mountains (Graf 1971) and in the Glacier National Park (Carrara 1986, Osborne 1985). Richmond (1986b) cites evidence for at least two Neoglacial advances in Yellowstone Park and Davis (1988) summarizes evidence for an as yet undetermined number of Neoglacial advances in the Absaroka Range.

The concept of a mid-Holocene interval of markedly drier climate, the Hypsithermal (Deevey and Flint 1957) or Altithermal (Antevs 1948) is commonly noted in paleoclimatological proxy records from throughout the northwestern United States. Davis and Osborn (1987) cite evidence for the lack of cirque glaciation during the early and mid-Holocene to argue for maximum warmth during this period of time. Palynological studies from northwestern North America suggest that this was a period of increased dryness, perhaps with warmer temperatures (Barnosky 1989, Baker 1983). Burkhart's (1976) study in the Big Horn Mountains failed to detect any evidence for significant Holocene vegetative change. However, he believes that his sites, which are located away from ecotonal areas, could not be expected to record evidence of relatively minor Holocene vegetative change in a mountainous area. Pedological evidence from archaeological sites in the Big Horn Mountains (Reider and Karlstrom 1987), and the Absaroka Mountains (Reider et al. 1988), provide support for a mid-Holocene elevation of the treeline, presumably associated with increased temperature.

Summary

Evidence from nearby mountain ice caps in Yellowstone Park, the Wind River Range, and the Big Horn Mountains, suggests that the late Wisconsinan ice retreat began ca. 14,000 yr BP, with readvances in Yellowstone Park and the Wind River Range occurring between 13,000 and 11,000 yr BP. By 10,000 yr BP ice had retreated into cirques high in the mountains. Evaluations of late Pleistocene climate changes are varied. Studies of ELA lowering suggest Pleistocene temperature depression between 10° (Locke 1990) and 16° C (Porter et al. 1983) below modern temperatures. Evaluation of frozen ground phenomena in the study area, and elsewhere in western North America, supports the interpretation from glacial fluctuations during the Holocene. From the glacial and periglacial proxy data for climatic change, it is not possible to determine when, and for how long, lowered temperatures existed. Both the limited paleontological and palynological data are interpreted to indicate harsh, cold late Pleistocene climates for the region.

With the onset of the Holocene, the climate of the Pryor Mountains region became warmer than during the Pleistocene. The mid Holocene may have been a time of warmer and/or drier conditions. The late Holocene is believed to have witnessed somewhat decreased temperatures, resulting in renewed cirque glacier activity, though conditions were nowhere near as severe as those estimated for the late Pleistocene.

MODERN ENVIRONMENT AND CLIMATE

Microclimatic variation is reflected in the diverse vegetation distributed throughout this mountain complex, from arid, cold desert in the Big Horn Basin and southern portions of the mountains, to subalpine park and meadows at high altitudes (South 1980). These differences relate primarily to low rainfall at the lower elevations in a topographic depression between the Beartooth and Big Horn Mountains, with greater, orographically influenced precipitation and lower evapotranspiration in the higher elevations.

The lowermost southern and western portions of the Pryor Mountains exhibit a typical Big Horn Basin vegetation, characterized by sagebrush (*Artemisia cana*, *A. arbuscula*), Juniper (*Juniperus utahensis*), and Pine (*Pinus ponderosa*) stands in protected areas. The vegetation clearly reflects the arid nature of the climate, with an average yearly precipitation of 166 mm recorded in the southern slopes of the Pryor Mountains (Lovell, Wyoming station) and 353 mm for the more moist, northern slopes (Billings station). Winter average temperatures are characteristically cold in both regions (Jan. -7.1° C: Lovell; -3.9°F for the northern slopes).

In the middle and upper elevations, vegetation communities range from often quite extensive sagebrush/grass meadows (*Artemisia tridentata* and *A. scopulorum*), to small, thick stands of trees including Limber Pine (*Pinus flexilis*), Lodgepole Pine (*Pinus contorta*), Douglas fir (*Pseudotsuga taxifolia*) and various spruce (*Picea engelmannii* and *Picea glauca*). Sage Creek station (located on the northern portion of the range at an elevation of 1690 m), records approximately 150-200 mm of precipitation, the bulk of which falls during May and June (Baker 1944). At this elevation, January temperatures average 1-11° C and July temperatures 13-32° C.

Vincent (1974) estimated the environmental lapse rate for the Pryors at approximately 10.32° C km⁻¹, a value very close to the dry adiabatic lapse rate. He suggests this lapse rate is applicable only for the summer, fall and spring months. During the winter, cold polar air masses invade the area, affecting lower elevations to a much greater extent than upper elevations. Locke (1989) estimated the environmental lapse rate for other western Montana mountain ranges at approximately 6° C km⁻¹, a figure more closely approximating the average environmental lapse rate (Battan 1974).

From a low in precipitation of 165 mm on the southern slopes of the mountains, the higher elevations receive more than twice as much precipitation (at least 370 mm annually) most of which falls in the spring and autumn as rain. Any precipitation falling between September and mid-May (and often later) is in the form of snow (Vincent 1974). The

calculated maximum precipitation gradient for the Pryor Mountains is approximately 234 mm H₂O km⁻¹. This figure is significantly lower than values reported from other western Montana mountain ranges (Locke 1989) and slightly greater than values reported in glaciated portions of mountainous areas in the Great Basin (Zielinski and McCoy 1987).

At the higher elevations snow drifts accumulate to substantial thickness, attaining heights up to 5 m where trapped by stands of trees, or in the wind shadow of the many cliffs and ridges. Open, wind-swept regions are bare to lightly covered with snow during much of the winter (personal observation and communication with National Forest employees). Melt-off occurs in mid to late spring in the mid to higher elevations. The higher elevations may retain a substantial snow cover in protected areas well into late July.

LOCAL LITHOSTRATIGRAPHY

Early Tertiary uplift of the Pryor and Big Horn Mountains followed upon uplift of the Beartooth Mountains during the Laramide orogeny. Sediments derived from the Beartooth Mountains can still be seen today on the Pryor Mountains as a thin lag of igneous gravels. The present form of the Pryor Mountains is a result of Pliocene erosion that produced extensive alluvial fans at the base of the mountains, landforms which are dominant features of the mountain flanks even today (Blackstone 1940).

The stratigraphy of the Pryor Mountains consists of a largely conformable, though discontinuous sequence from the Middle Cambrian through the Upper Cretaceous (Blackstone 1940, 1975: Figure 7). The bulk of the Pryor Mountain blocks are comprised largely of the Mississippian Madison Group. The overlying Amsden Formation (Pennsylvanian) consists of argillite, claystones, and siltstones, and is sporadically represented as the surface rock unit where not eroded away to expose the Madison Group carbonates. Dolomite of the Jefferson Formation is exposed in one area to the west of the Crooked Creek fault, where it has been thrust into a near vertical orientation. The upper Pennsylvanian Tensleep sandstone is exposed at the lower elevations on the southwestern flanks of the mountains.

The major mountain blocks are bounded by fault systems which also determine the courses of major streams that drain the mountains. The most extensive of these is the Crooked Creek fault system that runs roughly north-south, and separates Big Pryor Mountain from East Pryor Mountain.

The primary cave-forming rock in the Pryor Mountains is the Madison limestone of Mississippian age. The Madison Group is subdivided into three formations: the Charles, the Mission Canyon, and the Lodgepole Formations. The uppermost Charles Formation is not represented in the Pryor Mountains, but elsewhere is primarily an evaporitic unit. The Lodgepole Formation is the lowermost unit and typically consists of thin gray to gray-brown limestone, and dolomitic limestone beds separated by clay or siltstone partings. The Mission Canyon Formation ranges in thickness from 20 to 200 m and consists of massive brown to dark-gray, dense or finely crystalline, limestone or dolomitic limestone, that weathers light gray (Blackstone 1975). Being relatively resistant to erosion, the Madison Formation stands out as spectacular sheer cliffs bordering major and minor fault systems. It is in these cliffs that the majority of caverns and/or rockshelters were formed. Fault breccias and extensive micro-jointing are associated with portions of the Madison Formation in the vicinity of fault zones. In other areas, cave breccias, believed to form from the collapse of former caves, are common.

The bulk of mid and high elevation study sites were formed in Madison limestone. In several of the middle elevation sites adjacent to the Crooked Creek Fault, the bedrock is highly jointed, and in some places occurs as a fault breccia. The upper elevation sites are well away from these fault zones and have not been similarly affected. The low elevation sites were formed in Pennsylvanian Tensleep sandstone. This is a cross-bedded, calcite cemented, quartz sandstone.

FORMATION OF CAVES AND ROCKSHELTERS

Several authors have considered the evolution of caves in the Mission Canyon Formation of the Madison Group (Campbell 1977, 1978, Roberts 1961) and it is useful to review their ideas insofar as they may be applicable to some of the sites in the Pryor Mountains. In many instances the top of the Mission Canyon Formation is extensively brecciated (Roberts 1966, Campbell 1977, 1978) which has been taken to indicate the formation of caves and sinkholes during late Mississippian time and later collapse and infilling. It is recognized that many of the caves in the Mission Canyon Formation are infilled with red clay and gravels that resemble the red shale of the overlying Amsden Formation. Thus cavern formation, and development of widespread karstic topography is believed to have followed upon the deposition of the Madison Group. Infilling of these caverns occurred during Pennsylvanian time (the sediment acted to buttress the caves against the weight of later overlying sediment accumulations: Campbell 1977: 48). Many of these infilled features have subsequently undergone reexcavation to give them their present form. Erosion and reexcavation of these caverns is believed to have followed Pliocene uplift (Campbell 1977).

The fill in a number of the Pryor Mountain caves, as elsewhere in Montana (e.g. Big Horn Mountains), consists of a fine-grained, reddish (hematite-rich), or brown (limonite-rich) fill. This sediment is believed to have entered the caves during the Pennsylvanian via vadose water percolating through narrow fissures or, less likely, phreatic waters or through the cave entrance. Other caves are observed to have formed directly beneath the solution breccia from previous karstic features (Campbell 1973).

The shallower rockshelters mainly represent differential erosion of exposed bedrock that was, for one reason or another, more susceptible to erosion than adjacent segments. In these cases, a portion of the formation of the site was in all likelihood contemporaneous with occupation by humans and/or animals.

PRYOR MOUNTAIN STUDY SITES

A large number of caves and rockshelters were examined by the Pryor Mountain archaeological field school (run jointly by the Universities of Alberta and Maine at Orono), only a small number of which were examined by the author. The Pryor Mountain research group divided the area into high altitude (approximately 2590 m), middle altitude (approximately 1830 m) and low altitude (approximately 1379 m) portions (Bonnichsen et al. 1985). Approximate locations of the three site clusters are illustrated in a topographic profile across the Pryor Mountains (Figure 8). The discussion to follow in this chapter will use these divisions to separate the study sites into three groups each of which possess fairly similar local climates. As the two sites in each of the three areas lie in close proximity to one another, an assumption of similar macroclimate is believed to be valid.

The high altitude sites, all located near the summit of East Pryor Mountain, are small caves formed in Madison Group limestones. These sites occur within the subalpine plateau ecosystem as defined by South (1980). With only scattered clumps of trees, this area experiences strong snow drifting in winter, sometimes with drifts up to 6 m in height. The local bedrock for these sites varies from thinly bedded to massive crystalline limestone (Madison Group), with minor jointing or fracturing. The bulk of the mid-altitude sites are located in Crooked Creek Canyon or canyons tributary to it. As these sites lie along one of the major fault zones, the bedrock making up the caves is generally highly jointed. The low altitude sites are shallow rockshelters formed in Tensleep Sandstone on the Big Horn Basin portion of the mountains. A map view of the three site areas is presented in Figure 9.

HIGH ALTITUDE SITES: FALSE COUGAR AND CAVE ANN

Four small caves were excavated by the Pryor Mountain fieldschool near the summit of East Pryor Mountain. These sites are False Cougar Cave (24 CB 84), Cave Ann (24 CB 163), Cowboy Bob Cave (24 CB 80) and a pit cave (Shield Trap, 24 CB 91, Bonnicksen et al. 1985). Cowboy Bob cave had been backfilled following excavation by the time the author joined the project, so only general comments can be made. False Cougar Cave and Cave Ann were examined in detail during the course of archaeological excavation. Shield Trap is a vertical cave and was examined by Geppert (1984).

Both False Cougar Cave and Cave Ann fall near the lower edge of the subalpine plateau ecosystem (approximately 2500-2682 m) as defined by South (1980) and the climatic data to follow were taken from his report. These elevations on the eastern side of the Pryor Mountains receive between about 381 and 508 mm annual precipitation, of which about half falls as snow during the fall, winter and spring. Mean annual soil temperatures average between 2.8 and 5.5° C, suggesting that evapo-transpiration rates are low and much of the fairly low precipitation infiltrates into the subsurface. However, much of the snowfall is blown to more forested areas, or into protected sites in lee-side cliff situations. The frost-free season varies between 40 and 50 days, indicating processes associated with the freezing and thawing of water may be active throughout much of the year in favorable locations at these elevations.

Geppert (1984) analyzed the small mammal remains from the nearby Shield Trap, a pit cave located approximately 300 m west from False Cougar Cave. His study suggested the following Holocene paleoecological reconstruction for the local area near the summit of East Pryor Mountain: 10,000-9000 yr BP, moist parkland; 9000-7000 yr BP, moist woodland; 7000 yr BP to present, dry meadow.

Modern Sedimentation Processes in the High Altitude Caves

In late June and early July, when the author visited East Pryor Mountain, the cave entrances were all filled with snow, leaving the cave interiors isolated, and insulated from the outside climate. Examination of the snow filling the caves revealed the presence of only a small number of clasts (approximately .2/m³) weathered off the ceiling prior to the filling of the cave entrance with snow. Additionally, there was an absence of a thick deposit of coarse limestone fragments on the cave floors or in the form of a talus slope outside the caves. These observations, although extremely limited, suggest that coarse, clastic sediments are produced at a slow rate in the upper elevations of the Pryor Mountains.

There was no evidence of winter use of the sites (False Cougar Cave, Cave Ann, or Cowboy Bob Cave) by either ungulates or rodents. There was also no visible evidence of introduction of fine-grained sediment during the winter months in the form of dust coating of the drifted snow within the shelters or visible dust layers in sections excavated into the snow. Blockage of the entrance by snow drifts may effectively preclude this mechanism of sediment introduction, at least during the winter and spring months.

For both the upper elevation sites discussed in this chapter, it is unlikely that alternative routes of entry for coarse clasts exist (other than perhaps by humans). The slopes outside the mouths of both caverns are inclined out of the caves, or are nearly horizontal, precluding the transportation of sediment by spring melt-off into the caves. The porous structure of the modern organic rich surface strata further reduces the possibility of deep surface water flowing into the shelters. Dips of older strata indicate that meltwater introduction of fine-grained sediment was unlikely to have occurred even during earlier portions of the history of these caves.

The evidence for introduction of finer grained clasts from outside the cave is fairly strong. Examination of cracks in the walls and ceiling of all three high altitude sites showed clear evidence for the transport of fine-grained (sand-clay) sediment down joints and fractures that extend to the barren, or soil-mantled, bedrock surface above the sites. In all likelihood, the down-fracture transport of sediment occurs in spring to late summer, by

which time all the snow on the overlying surfaces has melted away, being preserved only in environmentally-favored localities such as in tree stands and beneath the rim-rock ledge. The total volume of sediment transported into caves and rockshelters by this mechanism is difficult to assess, though it is likely to contribute to the weight percentage of the fine fraction.

Finally, biological agencies, particularly rodents and ungulates, play a major role in modern sedimentation patterns. The surface layer of Cave Ann was extensively littered with rodent and ungulate dung, and packrats (*Neotoma* sp.) utilized interior portions of the caves as nesting sites. The undisturbed surface of False Cougar Cave was never investigated prior to excavation so its character is not known. However, from the large amount of identifiable organic matter in the surface stratum, dung is likely to have been a major component of the surficial sediment here as well.

The amount of inorganic sediment introduced by biological agencies is also difficult to assess, but certain lines of evidence suggest it may have been significant. Reduction of several 1000 ml beakers of identifiable animal dung (thru flotation and oxidation in hydrogen peroxide) consistently produced a thin film of very fine sediment (minor sand with abundant silt and clay). Although the sediment may not in fact have been contemporaneous with the organic matter, it is likely that the sediment coated the forage and passed through the digestive tract of the responsible animal. A further unquantifiable source of sediment in caves utilized heavily by mammals is the tracking in of muddy sediment and that adhering to fur. Finally, as noted below, coarse sand-sized, polished quartz and chert clasts, interpreted as the gullet pellets of birds, were commonly noted in the Unit I sediments. These clasts do not contribute significantly to the composition of the fine fraction in these samples.

Additionally, the caves in the high altitude area, as well as those in the other portions of the Pryor Mountains, were occupied by prehistoric peoples, as indicated by artifactual materials and inferred food remains. Although the activities of these peoples during their stay at these sites is speculative, the very small number of artifacts, and the small size of the shelters, suggests that they were not intensively occupied for long periods. Unlike the situation in European Paleolithic caves and rockshelters, it is unlikely that humans significantly altered the microenvironment of these sites for any great length of time.

FALSE COUGAR CAVE

Location

False Cougar cave (45°10'N/108°21'W) is situated near the summit of East Pryor Mountain at an elevation of approximately 2600 m. The site is a small solution cave, the horizontal extent of which is unknown as it is largely choked with debris approximately 3 m back from the entrance. Facing southeast, it overlooks a shallow, dry, southwesterly trending valley. The cave is formed in a shallow rim rock approximately 5 m high, the base of which is covered by a grass-covered colluvial slope. Around the corner from the cave to the south, the slope is littered with unvegetated talus where snowfields commonly persist into the beginning of July. Prior to excavation the cave was 3.0 m wide, 3.5 m deep and 1.0 m high (Bonnichsen et al. 1985: Figure 10). Notably, snow drifts accumulate to great thickness at the base of the small cliff, partially infilling and sealing the entrance to the relatively shallow cave. These drifts apparently last into July (personal observation) and must have played a major role in the microclimate of the cave during its history of development.

Stratigraphy

The exposed section of False Cougar Cave has been subdivided into three major lithostratigraphic units based primarily on differences in texture and organic matter content

(Figure 11). Subdivisions of these units, based on more minor differences in texture and color, are provided in Table 5.

Unit III overlies bedrock and consists of massive sandy silts, silty sands, and clayey silts, stained and mottled by iron oxides, and is interbedded towards the mouth of the cave with iron-oxide sand and gravel lenses. The basal sediment consists of a brown, clayey silt containing numerous polished chert pebbles. Bonnicksen (pers. comm. 1982) reported that chert microflakes were recovered from the screenwash concentrate from Unit III.

There is a sharp, though mottled, and probably unconformable boundary between Unit III and Unit II. Unit II varies in thickness between 70 and 120 cm, and dips fairly steeply down towards the cave mouth, filling in depressions in the underlying Unit III sediment. Numerous angular to subangular boulders and cobbles occur within Unit II. Towards the rear of the cave, there exists a portion of the unit where matrix-free boulders and cobbles support one another, suggesting sudden dislodgement of these large clasts from the cave roof. The base of the unit is heavily stained with manganese and hematite. Rare, thin, charcoal lenses are scattered within Unit II.

The boundary between Unit I and the underlying Unit II is diffuse, marked primarily by decreases in the amount of organic matter present. Unit I is a relatively thick (1.0-1.5 m) wedge of diamicton, thickening gradually towards and beyond the mouth of the cave, where it merges with the colluvial apron beneath the rim rock in which the cave is formed. The sediments consist of largely matrix-supported, subangular to subrounded, limestone clasts in a matrix of dark, organic rich, sandy silt to sandy silty clay. Primary distinguishing criteria for subdivision into microstratigraphic Units IA-ID1 are variations in the organic matter and limestone clast content. The former criterion has provided relatively sharp boundaries between adjacent units that were employed to excavate individual units. Within all of Unit I, limestone clast content increases toward the mouth of the cave, where it forms a jumbled clast-supported mass in which stratigraphic integrity was no longer recognizable.

A number of distinct charcoal lenses and charcoal-filled depressions in Unit I occur both within and without the cave. Throughout the remainder of the unit, charcoal flecks and chunks were scattered. Presumably, humans are responsible for the abundant charcoal in both strata, though windblown charcoal from nearby natural fires could be responsible for some of the dispersed charcoal flecks.

Age of the Sediment Accumulation

A number of C^{14} dates have been processed for False Cougar Cave and are presented in Table 6. These dates suggest that the sedimentary fill extends from at least ca. 14,000 yr BP in Unit II to the present, with an unknown length of time represented by the sediments in Unit III. However, within the dated portions of the section the dates are vertically inconsistent if all dates are included. For this reason, and because of the nature of the sample collection methodology, only those dates personally collected directly from the section wall will be considered. Those samples removed by excavators in the process of excavating loose sediment (where the potential for overnight wall collapse was a real) or from excavation screenwash are considered to be potentially contaminated and will not be discussed. The alternative is to accept all the dates and assume that there was considerable mixing upwards and downwards within the section.

Simply using the samples collected from the exposed section, a possible Pleistocene age of Unit III of >14,000 yr BP can be estimated. As discussed below, it is quite possible that Unit III significantly predates the onset of sedimentation in Unit II. Unit II was receiving sediment by 14,000 years ago, and possibly somewhat earlier. This unit then apparently spans the latest glacial and the period of time when this area experienced significant climatic change, as inferred from the studies cited earlier. Unit I appears to span the Holocene (<10,000 yr BP). These sediments may then reflect the climatic changes inferred for the early, mid and late Holocene in the western Cordilleran region.

In a general sense, paleontological remains recovered from False Cougar Cave support the radiocarbon chronology. Remains of horse (*Equus* sp.) and camel (*Camelops* sp.) were both recovered from Unit II (Bonnichsen et al. 1985), confirming a Pleistocene age for these sediments. In addition, skeletal elements of the collared lemming (*Dicrostonyx torquatus*), which today is restricted to arctic environments, was identified from Unit II as well as Unit IIIi sediments.

Sedimentation Rate

Using the radiocarbon dates collected from the section profile, it is possible to construct a series of sedimentation rate curves for False Cougar Cave (Figure 12). Dates were plotted on the vertical axis in terms of the depth of the sample below the relatively level surface of the cave fill. A further line was drawn from the lowermost sample to 0 cm depth to give an average curve for the sedimentation rate over the history of the shelter above the lowermost sample.

The calculated sedimentation rates indicate that sedimentation has been relatively constant over the last 14,000 yrs BP, with the possible exception of the uppermost section of the profile. It is possible that the more rapid sedimentation rate indicated for the last several thousand years is more apparent than real. The increased rate may simply involve compaction of underlying strata, as well as less organic decomposition in the uppermost strata. Using just the average value of 13 cm 1000⁻¹ years, it would appear that the rate of sedimentation at False Cougar Cave was both relatively constant and relatively slow for Units I and II. However, the presence of abundant large roof-fall blocks at the base of Unit II argue for a very rapid, perhaps episodic sedimentation rate prior to ca. 14,000 yr BP. At the end of this chapter I will compare rates for other Pryor Mountain study sites and in Chapter 7 compare these rates to all the sites discussed in this dissertation as well as the few other published rates from other shelters.

Due to the very different style of sedimentation in the lower strata at False Cougar Cave, it is impossible to extend the sedimentation rate for the upper strata down into Unit III. The sediments comprising Unit III lack evidence for the gravity fall sedimentation exhibited by the upper strata. These sediments appear to have washed in from as yet unidentified karstic fissures. The rate of introduction of this sediment is unknown.

Description of the Sediments

The discussion to follow summarizes the salient characteristics of the sedimentary strata exposed by excavations at False Cougar Cave. The text is keyed to Figure 13, in which sedimentological data pertaining to the Coarse (A) and Fine (C) fractions of samples are presented. Data for the Medium (B) fraction is presented only as a weight percent of the total sample in the histogram labelled granulometry. Methods of analysis and calculations were presented previously in Chapter 3.

Unit III

Strata in Unit III consist of several thick, irregularly shaped sediment bodies composed of clayey and sandy silts, interbedded with thin lenses of silty sand. The thick silt-rich beds exhibit wavy convolutions. Variable yet small quantities of clasts >1 cm occur within several of the strata, with Unit IIIj containing abundant matrix supported polished chert pebbles. There is an absence of carbonate clasts >1 cm in these strata.

The mean size ($Mz\phi$) of all sediments from Unit III lies in the range between very fine sand in the silty sand lenses, to fine silt in the lowermost stratum, Unit IIIj. The bulk of the units have mean sizes in the medium to coarse silt range. The sorting (σ_1) of these samples varied between poor and very poor. The coarser textured samples exhibit significantly better sorting ($<2\phi$) than the medium and fine silt samples ($>2\phi$).

The mineralogy of the medium (1-0.2 cm) and coarse fraction (>1 cm) sediment for all except Unit IIIj consists largely of friable, iron oxide clasts with occasional rounded chert clasts. The fine fraction contains <2% carbonates and consists of abundant iron oxide, chert and macrocrystalline quartz in the sand fraction.

There exists no source area for the sand and gravel portion of the sediments making up Unit III on the present bedrock surface above False Cougar Cave, although intraformational chert occurs within the Madison Limestone in which the cave formed. The only viable source area for the remainder of the sediments must be the iron-oxide rich siltstones and shales of the stratigraphically higher Amsden Formation. Boulders resembling the Amsden Formation occur very sparsely on the upper surface of East Pryor Mountain. As the mineralogy of the clay and silt fractions was not determined, it is possible that these sediments represent the weathered residue of the host limestone.

Units I and II

Coarse Fraction

There are 3 distinct modes in the pebble to granule range of the A fraction; 1): comprising Units ID1 and upper Unit II, 2): comprising Units ID and IC, and 3): the upper two Units, IA and IB. Viewing the granulometric curve even less critically, there are two modes; a very coarse gravel unit comprising upper Unit II and ID1 and the other, the four overlying units, exhibiting a significantly lower clast to matrix ratio. The two coarser units vary from 64.4 to 66.0% gravel (>2 mm) by weight and the overlying units vary from a low of 37.1% gravel in Unit IC to a high of 45.6% in Unit IB. The mean size of clasts in samples from Units I and II ranges from 5.0 cm in Unit ID to 6.5 cm in Unit ID1. There appears to be only a weak correlation between mean clast size and percentage contribution of the coarse fraction.

Throughout Unit I most of the clasts are subrounded, with virtually no angular clasts, though both subangular and rounded clasts are represented as well. Unit II also contains largely subrounded clasts also, though it differs in having a number of angular clasts with a corresponding decrease in the percentage of rounded clasts.

The presence of abundant subrounded and particularly rounded coarse-fraction clasts in all samples from Units I and II, indicates that substantial rounding of clasts occurred prior to dislodgement from the walls and ceiling of the shelter (Farrand 1975). The porosity of the coarse fraction clasts was not systematically measured for these samples. Given the porous, organic rich sediments making up Unit I, and the relatively low content of gravel-sized clasts, there seems little likelihood that the post-depositional rounding could be the result of mechanical wear. For these reasons, the high degree of rounding of these samples is attributed to post-depositional chemical weathering.

Secondary carbonate concretions were not observed on any of the clasts in samples from False Cougar Cave. Additionally, secondary precipitates were not visible on the walls or ceiling of the shelter. The absence of these features suggests that the thin soil mantle and sparse vegetation on the bedrock above the site do not create a situation in which either the percolating rain water or snowmelt dissolve CaCO_3 during the short journey down to the ceiling and wall rock of False Cougar Cave.

Fine Fraction

The fine fractions of all of the sediment samples from Units I and II are composed of very poorly ($\sigma_1 > 3\phi$) to extremely very poorly sorted ($\sigma_1 > 4\phi$) sandy, silty clays. The mean size of fine fraction sediments varies from 7.11 ϕ to 8.55 ϕ in the range of fine to very fine silt and clay. The percentage of sand in each sample is roughly constant though the clay content varies from a minimum (6%) in Unit II to a maximum in Unit ID (14.6%).

Quantitative mineralogical information on the fine fraction is not available. However, observations of the sand fraction under a binocular microscope revealed that the vast majority of sand-sized clasts are carbonate sand grains. Within every sample examined,

occasional very coarse, sand-sized, rounded and highly polished quartz or chert grains were noted. These clasts are interpreted as the gullet contents of some bird.

There is a clear peak in the organic matter content in Unit ID and another in the surface stratum, Unit IA, though organic matter content is relatively high throughout the section, excepting Unit III, where it is essentially absent. Unit II also has substantially lower quantities of organic matter. This distribution argues against a simple, time-dependent decay of organic matter down the section with a roughly constant influx of organic matter. Rather, these data suggest that organic matter decomposition has been relatively slow throughout the history of the shelter and that the rate of introduction of organic matter has varied through time. However, high values for organic matter in the surface stratum, given the presence of undecomposed feces and plant parts, features which are absent in stratigraphically lower strata, probably do relate to incomplete early stages of organic decomposition in this stratum.

There is a clear correlation between high and low values of organic matter and peaks and valleys in the clay mode (except in the surface Unit IA where limited decay is the likely cause). The explanation for this correlation is somewhat speculative. If increases in the organic matter content result from greater use of the cave by animals, then the correspondence between highs and lows in clay and organic matter content may relate to a greater frequency of clay introduction in animal feces or by tracking in on muddy feet and fur.

Deposition of the Sediment

Unit III

Unit III sediments have a mixed origin. The steeply dipping iron-oxide silty sand and gravel lenses interbedded with silt-rich strata (Figure 11) suggest erosion, transportation, and deposition by a current within the cave. As it is impossible to reconstruct a possible flow direction, or even the nature of the water body, detailed speculation is precluded. The origin of the under- and overlying finer-grained units is less clear. They may simply represent the deposition of fine-grained sediments in a standing body of water, however, the lack of any horizontal lamination, the poor sorting of the strata, and the presence of occasional large clasts would argue against this origin. Alternatively, the sediments may have slowly accumulated by the migration of fine-grained clasts through cracks and crevices in the ceiling and walls of the cave. Subsequent slumping of saturated silty sediment into erosion hollows and/or loading of water-rich silts, would then account for the observed convolutions and apparent in-unit gravel lenses.

The sand fraction and gravel fraction clasts within Unit III are a mixture of non-local, iron oxide clasts and chert clasts that might have been derived from the local limestone or have been transported in from elsewhere. Unit IIIj, a clayey silt with abundant chert pebbles, lacks the iron-oxide gravel-sized clasts characteristic of overlying Unit III sediments. As Unit IIIj directly overlies bedrock, filling in hollows in the floor of the cave, these sediments represent the earliest portion of the sedimentary record. Given the great disparity in size between the fine silt matrix and the chert pebbles, I believe that Unit IIIj represents deposition by two different processes. The fine fraction, given the lack of carbonates, may be partially derived from fine residue in the local rock, though a portion may have washed in, perhaps by very low velocity seepage or flow, from as yet undiscovered karstic passages in the rear of the cave. The origin of the chert pebbles is uncertain though they may also be residual from the host limestone.

Any interpretation of the origin of the Unit III sediments must consider the mineralogy of the sediments. All sediment samples contained less than 2% soluble material and great quantities of minerals uncharacteristic of the host bedrock making up the cave. These grains, consisting predominantly of quartz making up the red sand lense of Unit IIIe, crystalline quartz prisms scattered through all the Unit III sediments, and abundant iron-

oxide (hematite and limonite) make up a considerable portion of the mineral assemblage in Unit III sediments. The most logical source for the Unit III sediments is the hematite-rich siltstones and shales of the Pennsylvanian Amsden Formation which stratigraphically overlies the Mississippian carbonates in which False Cougar Cave formed. The Amsden Formation is abundantly exposed at lower elevations on East Pryor Mountains, but does not crop out within the area in which False Cougar Cave is located but instead occurs as isolated boulders or gravel on the surface above the cave.

The various lines of evidence discussed for the Unit III sediments argue for a very different cave environment during the formation of these sediments as opposed to the overlying sediments. The lack of organic matter, except for rare remains of small mammals, the lack of carbonates, either in the fine fraction or as gravel-sized clasts, and the extra-local mineralogy of virtually the entire sediment assemblage, suggest that False Cougar Cave was closed to the introduction of sediment from an entrance similar to the present one, possessed a stable cave microenvironment, and received abundant sediment from some source within an interconnected karstic system. Support for this hypothesis is also forthcoming from the termination of Unit III sediments against a bedrock sill beneath the modern cave brow. As Unit III does not occur in the excavations outside the modern cave, it can be assumed that either these sediments were never there to begin with or were subsequently removed by erosion.

If the modern entrance existed during Unit III time, it seems inconceivable that local carbonate sediments would not have been deposited, either from exterior sources, or as gravity-fall debris from the ceiling and walls of the cave. A closed system would have resulted in very stable cave temperature, and a fairly constant relative humidity, both of which might have caused an extremely slow rate of mechanical weathering of the shelter's walls and ceiling.

The lack of organic matter and small yield of small mammal remains may be supportive of a closed system environment for False Cougar Cave. On the other hand, these data may simply indicate that the wet cave environment, suggested by the evidence for at least periodic fluvial inundation, made for an inhospitable nesting area.

The presence of an extra-local mineralogical suite, with evidence for fluvial transportation and deposition of sediment, combined with the dip of the strata, argues for the existence of a former connection to an as yet undiscovered karstic system somewhere in the now sediment filled rear areas of the cave. As reported by Campbell (1977, 1978), many karst cavities in Mississippian carbonates of Montana and Wyoming are choked with a red clay or silty fill resembling the overlying Pennsylvanian Amsden Formation sediments.

Thus, it seems most probable that, prior to being choked with sediment, a karst passage allowed access to flowing water (perhaps only seasonally) which introduced iron oxide and quartz rich sands and silts, and gravel-sized clasts of chert and iron oxides into the cave. At some later date, the passage must have become sealed and the modern entrance to False Cougar Cave opened, allowing access of the outside climate into the cave environment. This event may be represented by the abundant, clast-supported roof-fall blocks at the base of the overlying Unit II.

The weakness of this hypothesis lies in designating a source for the water and a passage into and out of the cave. Unit III sediments terminated against a large bedrock sill beneath the modern entrance to the cave. The walls of the trench abutting this sill were lined with Unit III sediments, so any possible drainage channel must lie buried beneath these sediments.

It is difficult to speculate on the age of the Unit III sediments if the hypothesis of a closed cave system is accepted. Filling of the cave could conceivably have occurred at any point following the formation of the karst topography on the surface of the Mississippian carbonates and following the deposition of the Pennsylvanian siltstones and shales. Given the presence of a small, yet fully modern (late Quaternary) fossil assemblage in several of the strata, it is impossible that all of the fill making up Unit III represents cave filling during

the Paleozoic. However, the mineralogical suite comprising Unit III could easily have been derived from formerly overlying sediments of the Amsden Formation. The most simple explanation, given the limited data, is that Unit III sediments washed into False Cougar Cave sometime during the Quaternary from sediment storage areas somewhere within the karstic system of which False Cougar Cave is in all probability a part. The initial storage of sediment may well have occurred during erosion and karst development following deposition of the Amsden Formation.

Units I and II

The base of Unit II, with its large boulders, high gravel content, and general high clast angularity, suggests, for at least portions of the unit, very rapid deposition. The presence of voids between large boulders supports this interpretation. The most probable explanation for the apparent rapid infilling of the shelter is due to a structural collapse of the cave ceiling, possibly associated with opening of the cave environment to the exterior climate, as argued above. It is unlikely that the roof-fall episode is related to late Pleistocene climatic change, though weakening by prior physical weathering processes might well ultimately have been responsible for the collapse (an alternative suggestion is that an earthquake in the region dislodged the material and opened the cavern to the exterior). Following roof-collapse, sometime during the late Pleistocene, sedimentation proceeded at a slower rate, infilling some of the voids between larger clasts.

During the deposition of Unit II, significant quantities of organic matter were first introduced into the cave. In all likelihood, this organic matter can be traced to utilization of the cave by rodents and possibly ungulates (as well as owls). It is possible that increased organic matter content of strata overlying Unit II are due in part to the development of a level surface, suitable for nesting sites.

The bulk of Units I and II sediments are locally derived carbonate clasts, the origin of which is easily explained in terms of simple mechanical/chemical weathering of the ceiling and walls of the shelter. Certainly, this is the case for the medium and coarse fraction sediment. As discussed earlier, a not insignificant portion of the fine fraction may have derived from both transport of sediment down fissures in the cave ceiling, and introduction via biological agencies. It is currently impossible to separate sediments introduced into the cave by these processes from gravity fall deposition of sand, silt, and clay-sized clasts. It is also impossible to distinguish the further size reduction of clasts >2 mm down into the finer sizes.

The higher gravel fraction percentages in Unit II and Unit ID1 must be explained by a greater production of coarse clasts relative to finer sediment than that present during the deposition of the upper four units. A similar, though smaller magnitude change in the rate of production of coarse clasts was also noted for the upper two strata, Units IA and IB, relative to Units IC and ID. As no other explanation for changes in the rate of production of gravel sized fragments is apparent, the observed changes in weight percent of coarse clasts is believed to have resulted from changes in either the cave micro- or macroclimate. A tentative correlation of these strata to regional paleoclimatic schemes will be discussed in a later section.

Units II and ID1 are further distinguished on the basis of a marked increase in the organic matter content in Unit ID1 over Unit II, and a greater angularity of clasts in Unit II. The greater percentage of angular clasts and lower percentage of subrounded and rounded clasts in Unit II are likely the result of a lower degree of post-depositional chemical alteration of Unit II clasts. Above Unit II, angular clasts are not important in the coarse fraction, indicating greater rates of alteration of these clasts.

The increased organic matter content of strata overlying Unit II is correlated with marked increases in the clay fraction values of upper strata. As argued in a previous section, the increase in the silt and clay component of the fine fraction may indicate increased use of the cave by animals. Additionally, these higher values may result in part

from elevated rates of introduction of fine sediment through fissures that may have existed above the cave.

A sharp decline in the microenvironmental conditions conducive to the formation of coarse limestone clasts is indicated for Units ID and IC by decreases in the relative contribution of this size fraction to samples from these strata. Clasts in Units IC and ID exhibit decreased percentages of subrounded and rounded specimens, indicating decreased local moisture levels conducive to the post-depositional rounding of clasts. It is possible either that the decreased moisture levels relate to decreased local precipitation or greater time in contact with moist sediment due to the more clay rich character of the ID sediments.

The increased values in organic matter in Units IC and ID may signal the accelerated use of the shelter by a variety of rodents, ungulates, and probably, hominids. Nesting materials, dung, and carcasses are all likely contributors to the increased organic matter content, and in conjunction with this increase there is a similar increase in clay fraction in these strata.

The deposition of sediment in the uppermost strata, Units IA and IB, witnessed a small increase in the rate of production of coarse clastic debris over Units IC and ID. Clasts in these two uppermost strata are somewhat more angular than Units IC and ID. This evidence for decreased post-depositional rounding of coarse clasts may indicate decreased moisture levels or, perhaps more reasonably, a more limited residence time in the deposits. The greater porosity of Units IA and IB (due to lower clay percentages and less organic matter decomposition) may also have affected the degree of clast rounding evidenced by the two surface strata.

Correlation of the Strata

Variation in the coarse clast content and morphology in Units I and II is most readily explained in terms of a changed cave microclimate during the span of time represented by these sediments: 1) a more rigorous regional climate, involving a depression in mean annual temperature, increased winter temperatures or fewer yearly freeze-thaw events during Units IC and ID times; 2) increased moisture, either in terms of increased local precipitation, distribution of precipitation throughout the year (e.g. increased snowfall), or some microclimatic variable leading to a less moist cave microclimate. Neither one is determinable on the basis of these data alone (see review of research section). For example, increased regional mean annual precipitation on the upper elevations of East Pryor Mountain would not necessarily promote increased weathering of the ceiling and walls of the shelter unless it came into contact with the rock surfaces of the cave, in sufficient quantity, and during the proper time of year or day. No net change in mean annual precipitation, on the other hand, but increased snowfall and accumulation as drifts within the shelter, would certainly have promoted greater rates of bedrock disaggregation by any of the methods suggested in Chapter 2. With these comments in mind, the following paragraphs will attempt to correlate the strata in Units I and II at False Cougar Cave with proxy evidence for climatic change elsewhere in the region.

The pattern of changes in coarse fraction percentages, combined with radiocarbon dates available for the section make it tempting to correlate these strata to independently derived paleoclimatic data elsewhere in the area. The maximum rates of coarse clast production evidently occurred during Unit II and ID1 times, during the latest Pleistocene and early Holocene. Evidence from a variety of sources suggest that mean annual temperature was certainly lowered during the late Pleistocene, although the temperature distribution across the seasons is not well understood. Certain lines of evidence, including advances of late Pleistocene or early Holocene mountain glaciers, and the Shield Trap small mammal record, suggest that this period may also have experienced greater precipitation than the mid-Holocene. Pollen evidence for the late glacial vegetation in the Big Horn Mountains also indicates a cold, moist environment. Both of these factors, decreased temperatures (if

associated with greater freeze-thaw frequency) or increased local effective moisture, should have acted to accelerate physical disaggregation of the shelter's ceiling and walls.

The widely cited evidence for decreased moisture levels, with or without increased temperatures during the mid-Holocene may be represented by the evidence for decreased rates of coarse clastic production off the ceiling and walls of the cave in Units IC and ID. The most significant source of moisture in False Cougar Cave today, and likely in the recent past, is the introduction of thick snow drifts into the cave. The cave is relatively dry in summer so it is difficult to imagine how decreased summer precipitation would have affected weathering rates within the cave. Decreased snowfall in winter or spring, or any process leading to less snow drifting into the cave would likely result in decreased rates of rockwall weathering at the site. Alternative explanations to a local decrease in snowfall could be simply the presence of a thick stand of trees in front of the cave entrance, blocking the drifting of snow into the cave mouth.

Slight increases in coarse clast content, and increases in the angularity of the two uppermost strata may be tentatively correlated to the regional climatic changes associated with the post-Hypsithermal, late Holocene Neoglaciation, recognized by advances of cirque glaciations in mountainous western North America. There is however, no independent evidence for either increased moisture levels or temperatures in the small mammal record from Shield Trap (Geppart 1984).

Discussion

False Cougar Cave provides an example of a cave receiving different kinds of sedimentary products as a result of varied sediment sources and evolution of the morphology of the shelter, as well as inferred fluctuations in climate. As expected from the rigor of the local subalpine climate, the mean clast size and the percentage of gravel fraction within sedimentary units was relatively high. The influence of changed freeze-thaw regimes and/or increased local moisture in the form of snow may have affected the changing percentages of coarse clasts in the deposit.

The relatively high roundness values are inconsistent with the classic interpretation of clastic sediments forming under a relatively cold climate. Clast roundness is most readily attributable to one of three processes; solution rounding of clasts while still attached to the walls and ceiling of the cave, post-depositional solution rounding of clasts, or post-depositional mechanical rounding of clasts due to solifluction (Farrand 1975). Given the lack of positive evidence for soliflucted sediments, this process can be excluded from discussion. The fact that the bulk of clasts are subangular to subrounded versus angular or rounded suggests significant rounding of clasts while still attached to the walls and ceiling. The presence of fully rounded clasts approaching 20% of the sample in all but Unit II suggests active post-depositional solution rounding.

Given the above evidence, it is safest to attribute the high degree of rounding to the "wet" local climate of False Cougar Cave. The source of moisture is most readily attributable to wind driven snow drifts. The slow rate of melting of snow within the shelter would have produced a long term exposure to moisture throughout the spring and summer months. It was difficult to separate time dependent rounding of clasts from variable rounding of clasts due to textural factors promoting moisture retention or differing precipitation (snow or rain) in the local climate of East Pryor Mountain.

CAVE ANN

Description

Cave Ann (45°09'N/108°18'W) is a relatively deep (greater than 10 m explored) cavern (Figure 14) that faces to the southwest, approximately 1.3 km to the northwest and across a dry valley from False Cougar Cave at an elevation of approximately 2566 m. The cave has a narrow mouth (ca. 3.3 m wide by 1.5 m high) opening out from a limestone ridge (Madison Group) beneath a small plateau at the summit of East Pryor Mountain.

Prior to excavation, the floor of the cavern was covered with masses of dung (rodent, deer, or sheep), as well as cones and twigs apparently introduced into the cave as nesting materials. In the rear of the cave there is an abandoned packrat midden of unknown antiquity. The floor of the shelter slopes gently up towards the rear of the cave from where it continues for an undetermined distance. Around the cave mouth, just beyond the drip line, there are numerous relatively large roof-fall blocks. Within the shelter proper, there existed only a small number of detached limestone clasts on the dung covered surface.

A single 1 x 2 m trench was excavated to bedrock just behind the drip line, revealing a shallow sediment accumulation (ca. 1.2 m) with only minor variations in sediment characteristics down the section. A small sample of archaeological and paleontological materials was uncovered from the deposits. The discussion to follow will be somewhat brief, both because less time was spent by the author investigating this shelter and due to the loss of much of the data for the fine fraction of sediment samples from this site.

Cave Microenvironment

Cave Ann appears to have a very dry cave microclimate. The evidence comes from the well-preserved, desiccated rodent dung and packrat midden within the cave. The dry microclimate is today aided by the presence of a thick stand of spruce (*Picea engelmanni*) and fir (*Abies lasiocarpa*) directly in front of the cave entrance. These trees, combined with the uphill slope to the floor of Cave Ann, preclude introduction of large quantities of windblown snow into the cave. It is impossible to determine the extent to which the vegetation windbreak existed in the past.

Stratigraphy

The small excavation unit at Cave Ann revealed a relatively homogeneous sediment accumulation with only very minor variations to bedrock. Throughout the profile, the sediments consisted of an organic rich, clast-deficient, sandy-silty-clay diamic. The small numbers of clasts >1 cm present preclude meaningful quantitative analyses of the gravel fraction.

The shallow section profile was divided into five lithostratigraphic units (Figure 15) on the basis of variations in the organic matter content and the color it imparted to the sediment, as well as the relative abundance of coarse limestone clasts in the sediment. In addition, several units were marked by an abundance of relatively unmixed, powdered carbonate sand and silt. Descriptions of the lithostratigraphic units are presented in Table 7.

Characteristics of the Sediment

Samples from Cave Ann contained a relatively small A-fraction (Figure 16), in contrast to the section exposed at False Cougar Cave. The minimum gravel percentage was 1.0% in Unit III, with a maximum of 27% in Unit V. There was not a sufficient number of clasts for statistically significant analysis of roundness, however, the majority were angular to subangular only a few subrounded specimens. No rounded clasts were noted during a visual examination of the samples.

Textural as well as dated for organic matter content were lost except for samples from Unit III and IV. The fine fraction from these two units consists of poorly-sorted ($\sigma_1 > 2.0\phi$), sandy, silty, clays. All sedimentary units contain a significant proportion of organic matter, estimated visually as greater than 10%. Identifiable organic matter in the form of rodent and other herbivore dung was present in the upper two strata. Only the lowermost units, in particular the whitish carbonate powder underlying Unit V, lack appreciable quantities of organic matter.

Age and Rate of Sedimentation at Cave Ann

No radiocarbon dates have yet been processed from Cave Ann. Additionally, the lack of identified late Pleistocene faunal elements makes any estimate of the age or rate of sedimentation at Cave Ann difficult. The presence of undecomposed organic remains on the surface suggests a modern age for these sediments. The lowermost strata may have begun to accumulate at any point during the late Quaternary. Extension of the sedimentation rate from False Cougar Cave gives an estimate of approximately 10,000 years for the onset of sedimentation in Unit V. This estimate is probably not realistic for Cave Ann due to the low quantity of coarse limestone clasts at this site, indicating a slower rate of production of gravel-sized clasts, assuming a relatively constant production of finer sediments between the two sites. Additionally, the looser, more friable nature of the sediments at Cave Ann indicate less compaction, and that any estimate of the sedimentation rate should be somewhat lower to account for this. I would suggest that, if anything, the sedimentation rate at Cave Ann is somewhat slower than that at False Cougar Cave. There is, however, no evidence to evaluate the reliability of this estimate.

Site Formation

Prior to major opening of the cave it is likely that only minimal clastic sedimentation occurred, primarily in the form of the sand and silt sized limestone fragments at the base of the section. With the opening of the shelter during the early to mid-Holocene (age determination based on limited recovery of stone artifacts), sedimentation in the form of organic matter introduction from outside and cryoclastic spalling within the shelter ensued. The narrow opening of the cave, in addition to the slope of the floor likely produced a situation in which temperature fluctuation within the shelter was minimal. Perhaps more importantly, the dryness of the cave, indicated by well-preserved, desiccated dung and packrat middens, would have minimized cryoclastism. The major sources of sediment introduction would have been the introduction, via zoological agencies, of abundant organic sediment and minimal production of coarse spalls from the cave ceiling and walls.

Discussion of Cave Ann

The small quantity of coarse fraction clasts and the loss of the fine fraction data preclude anything other than very general comments about the sediments composing Cave Ann. The similarity in the relative changes in the percentage contribution of the coarse fraction to values in False Cougar Cave make it tempting to correlate these strata. However, the small total number of clasts in each sample from Cave Ann is not large enough to make statistically significant comments about the variation through time in the coarse clast content. Instead, it should merely be emphasized that the coarse fraction content is very low (maximum of 27%) in all samples from this site. Further, the lack of radiocarbon dates makes any correlation to nearby sites or regional climatic schemes dubious.

DISCUSSION OF HIGH ALTITUDE SITES

The sediments making up both high altitude sites were characterized by introduction of abundant organic matter, mostly in the form of animal dung and nesting materials for small mammals (e.g. Marmots, *Marmota* sp., and packrats, *Neotoma* sp.). It is quite likely that

the frequent use of these caves as refuges for small mammals resulted in the introduction of significant quantities of fine-grained, clastic sediments as well.

There is little similarity between the two caves in the production of clastic sediment. Cave Ann has only a minor production of coarse limestone clasts, while in False Cougar Cave clasts >1 cm accounted for more than 50% of the sediment in many stratigraphic units. In addition, there is a great deal of dissimilarity in the roundness of clasts, although clasts from Cave Ann were not analyzed quantitatively. The coarse fraction clasts from Holocene units at False Cougar Cave contained very rare angular clasts and a considerable proportion of rounded clasts. Cave Ann, on the other hand, yielded no rounded clasts and at least small quantities of angular specimens in samples with a significant proportion of clasts >1 cm for qualitative evaluation.

These two sites occur similar elevations, and are separated by only 1.3 km, yet the sediments comprising their fills are very dissimilar. It is believed that the differences in the clastic products at the two sites are due primarily to the lack of frequent physical weathering of the cave rock in Cave Ann, whereas False Cougar Cave experienced a relatively greater rate of ceiling and wall physical disaggregation. The reasons behind the greater rate of physical weathering probably have to do with a greater influx of moisture in False Cougar Cave (from long-lying snow drifts) and decreased diurnal freezing and thawing in the less exposed situation at Cave Ann. The greater rounding values at False Cougar Cave also probably relate to more frequent and more prolonged contact with moisture. Judging by the quantities of dung and other organic debris, the introduction of organic matter at Cave Ann proceeded more quickly than at False Cougar Cave, probably a result of its more protected location.

MIDDLE ALTITUDE SITES: BIG LIP ROCKSHELTER AND CRYSTALSIN CAVE

A number of rockshelters and caves were excavated in the mid-elevation areas of the Pryor Mountains. Most of these are located on or adjacent to Crooked Creek, which flows along the Crooked Creek Fault zone separating Big Pryor Mountain from East Pryor Mountain (Figure 17). Crooked Creek flows in a progressively deeper canyon with near vertical walls in its mid and lower canyon reaches.

A large number of the mid-elevation sites are breccia-filled caverns (Campbell 1977, 1978). Presumably these represent ancient filled karst systems that were truncated by the Tertiary regional uplift events which produced the Crooked Creek canyon, and were subsequently reexcavated by more recent weathering. Many other breccia-filled caverns visible throughout the Crooked Creek drainage are in varying stages of removal of the breccia filling.

The mid-elevation area is semi-arid, receiving between 380 and 482 mm of precipitation annually. Like the higher elevation areas, the mid-elevation areas experience a low mean annual soil temperature ranging between 5-7° C. The frost-free season is significantly longer, varying between 40 and 90 days.

Big Lip Rockshelter and Crystalsin Cave were examined in conjunction with the excavations by the Pryor Mountain field school. Big Lip Rockshelter is a small reentrant at the base of a limestone cliff along a small tributary to Crooked Creek, and Crystalsin Cave is a small cave located near the rim of Crooked Creek Canyon, some 100 m above the creek. A number of other unexcavated caves and rockshelters were examined in the mid-elevation area.

BIG LIP ROCKSHELTER (24 CB 74)

Physical Description and Location

Big Lip Rockshelter (45°08'N/108°26'W) is a relatively shallow (5 m deep), low (2.5 m high), wide (9.6 m wide: Figure 18) reentrant weathered into breccia and heavily jointed Madison Group limestone at an elevation of approximately 1847 m. The prominent lip mound beneath the shelter brow stands about 1.5 m above the shelter floor which slopes downward towards the rear of the shelter. A steep slope also exists from the southwest portion of the shelter to the northeast. The mouth of the shelter faces approximately south, however access to solar radiation is hindered by the vertical north facing canyon wall opposite the cave. The cave appears to be very dry in summer, and has served as an animal nesting ground in the recent past. A 1 m x 2 m test trench was excavated into the site in 1979; below about 1.5 m, the excavation was restricted to a 1 x 1 m pit.

The shelter is located immediately to the north of Wyoming Creek, a small tributary of Crooked Creek, which flows through a short, steep-walled canyon that narrows to a neck immediately downstream of Big Lip Rockshelter. For a little over 100 m upstream and downstream of the site, the canyon floor has a relatively gentle grass-covered slope. Topographic relief upstream of the site is provided by several abandoned terraces formed through downcutting of Wyoming Creek. Upstream of the meadow area, the valley gradient steepens markedly up the east face of Big Pryor Mountain. The headwaters of the Wyoming Creek drainage consist of several now-vegetated nivation hollows that support snowpatches through a large part of the summer.

The steep gradient portion of the Wyoming Creek valley, immediately upstream of the meadows adjacent to Big Lip Rockshelter, is interpreted as the remnants of a former period of valley aggradation. The sediments, where exposed, are very poorly sorted matrix-supported gravels and boulders with interbedded sandy gravel strata.

In its downstream segment, in the vicinity of Big Lip Rockshelter, and down to its confluence with Crooked Creek, Wyoming Creek meanders through a silty sand alluvium with occasional large boulders. The narrow stream bed lacks a significant gravel fraction and apparently only transports sediment finer than pebble size in the lower gradient, downstream parts of the valley.

Stratigraphy

The sediments exposed in the excavation can be divided into two broad units (Figure 19); the upper approximately 1.5 m (here referred to as Units Ia-c) consist of subangular to subrounded, clast supported limestone gravels, with a dark, organic-rich, poorly-sorted, sandy silty clay matrix, interbedded with several discontinuous charcoal lenses and occasional patches of reddened sediment. All of the cultural materials and the bulk of the paleontological materials were collected from Unit I.

The boundary to the underlying Unit II is sharp and, given the dramatic lithologic change along this boundary, suggests an erosional unconformity. Unit II is a uniformly organic-free sediment accumulation, exhibiting well-rounded clasts of all sizes, and ranging from 5YR to 7YR in color referred to as Units IIa-h. The latter units consist of alternating coarse and fine textured sediments. Descriptions of sediment variation within the major units is provided in Table 8.

Age of the Sediment Accumulation

Three radiocarbon dates were processed from Big Lip Rockshelter and these dates and their locations are plotted on the profile in Figure 19. The lowermost charcoal sample from a lense-shaped charcoal feature excavated into unit IIa yielded a date of 7560 ± 500 yr BP (B-5763). A small charcoal lense at base of Unit IA produced a date of 2700 ± 80 yr

BP (B-5755). Charcoal from the mid portions of Unit IA yielded a date of 260 ± 70 yr BP (B-5754).

These C^{14} dates suggest that Unit I sediments began to accumulate sometime in the early Holocene and that deposition continued until the present. The age for the earlier Unit II sediments is unknown though logically they must have formed sometime during the late Pleistocene/early Holocene.

Sedimentation Rate

A curve of the rate of sedimentation based on the three radiocarbon dates from Big Lip Rockshelter is drawn in Figure 20. These data suggest that the sedimentation rate for Unit I sediments at Big Lip Rockshelter has been fairly constant through time, except for an apparent increase in uppermost Unit Ia. Again, as suggested for False Cougar Cave, the apparent increase in the rate of sedimentation for the uppermost sediments may relate to differential compaction and a greater quantity of undecomposed organic material in the surface sediments. Overall, the sedimentation rate is similar to False Cougar Cave, indicating fairly constant, slow sedimentation. Given the evidence for minimal human occupation and the lack of unconformities within Unit I, the calculated average sedimentation rate of $13 \text{ cm } 1000^{-1}$ years is probably an accurate reflection of the rate of filling of this shelter throughout the early to late Holocene.

As will be discussed below, the great difference in mode of sedimentation precludes extension of the sedimentation rate for Unit I into the underlying Unit II sediments. I suggest that the sedimentation rate for these sediments was significantly greater, although with episodic periods of erosion.

Characteristics of the Sediment

Sedimentological data for samples from Big Lip Rockshelter are presented in Figures 21 and 22. Sediment samples from Unit II were described in the field and the coarse fraction was subjected only to gross granulometric analysis and qualitative lithological examination in the laboratory. The small size (in terms of clasts $>1 \text{ cm}$ recovered) of the Unit IC sample precludes detailed observation of the morphology of clasts from this sample.

Units IIa-h

Coarse Fraction

Units IIa-h consist of alternating beds of poorly to very poorly sorted, fine textured to very coarse textured strata (Figure 21). The larger (greater than sand-sized) clasts are carbonate gravels (predominantly limestone with more minor dolomite). The yellowish to reddish colors in the fine fraction result from considerable admixture of iron-oxide sand-sized clasts (this observation is supported by visual microscopic mineralogical observation). The clasts greater than 1 cm in maximum dimension are uniformly rounded.

Fine Fraction

The fine fractions of Unit II samples are uniformly free of organic matter (Figure 22). Samples vary from sandy silts to silty sands, all of which are very poorly sorted, slightly fine-skewed to symmetrical, with one strongly coarse-skewed sample, and largely leptokurtic, with one platykurtic sample. pH values for samples vary from 7.5 to 8.0.

Unlike the overlying Unit I samples, those of Unit II are variably enriched in dolomite, in several samples comprising a larger percentage of the carbonate fraction than calcite. In all probability, the high dolomite values reflect downvalley transport of dolomite clasts from an exposed dolomite ridge near the headwaters of Wyoming Creek and its tributaries (Figure 17).

Units Ia-c

Coarse Fraction

The coarse fraction of Units Ia-c makes up a large percentage of both Units Ia and b (over 60%; Figure 21). The mean size of clasts in Unit Ib (6.55 cm) was higher than in the surface unit Ia (5.65 cm). The greater coarse to fine fraction percentages indicate that production of coarse clasts has exceeded the rate of production or introduction of fine fraction sediment, either during initial sedimentation or with subsequent post-depositional size reduction.

The majority of clasts in both samples were angular to subangular, with subunit Ib exhibiting somewhat greater angularity of clasts than the surface unit, which yielded small percentages of rounded clasts. High values for subangular and subrounded clasts are interpreted to indicate rounding of clasts while still attached to the shelter walls and ceiling. Only Unit Ia, where there are rounded clasts, has evidence for significant post-depositional rounding of clasts.

In contrast to the sites reported at the upper elevations, secondary carbonate precipitates ("P" concretions) were present on clasts making up the sediments in Unit I at Big Lip Rockshelter. Secondary carbonate concretions were significantly more abundant (nearly 15%) on clasts in subunit Ia, covering the surface of less than 5% of the clasts in Unit Ib.

Fine Fraction

Organic matter content achieved somewhat higher values in the surface Unit Ia, but in both Unit I subunits constituted over 15% of the sample. Organic matter content decreases down the section, to absence in the lowermost strata. The primary source for organic matter introduction appears to have been animals. The distribution of organic matter content in these samples may be due changing use of the shelter by animals through time, or progressive decomposition of organic matter in lower strata. Given the dry state of the shelter, at least during the warmer months, and the granular, porous structure of the sediments, I suggest organic decomposition as the most probable explanation.

The dominant size fraction is silt-sized, though nowhere does this fraction exceed 50% of samples. The mean size ranges from 6.06 ϕ to 5.38 ϕ (medium silt). Clay values increase down the section with a corresponding decrease in sand-sized clasts. This downsection change, as well as that involving the downsection decrease in organic matter, may indicate diagenetic alteration of the sediments. Alternatively, the decreased coarseness of samples from Units Ib and Ic may monitor slopewash activity as suggested by geochemical data (see below). All the sediment samples are very poorly sorted, slightly fine-skewed, and platykurtic. pH values for all samples range between 7.5 and 7.6.

Relatively low values for calcite (<40%) suggest that a considerable introduction of non-carbonate sediments has occurred. Qualitative examination of the sand fraction indicates the presence of quartz and iron oxides clasts in this fraction, similar to those noted for the samples from Unit II. These sediments are most likely derived by slopewash from the rockshelter sides as well as over the brow. The absence of dolomite in the Unit I fine fraction is striking when compared to Unit II sediments, and is taken to indicate a halt in the significance of Wyoming Creek as a sediment source for the fine fraction at Big Lip Rockshelter.

Formation of the Sediments

The textural and morphological evidence from the two major lithostratigraphic units argues for a very different mode of sediment formation in each one. The earlier sediments forming Unit II appear to be derived from alluvial transport down Wyoming Creek, with additional colluvial introduction from the hillslope to the west of the shelter. An alluvial origin is indicated by the rounded and polished clasts, considerably better sorting of the fine fraction, and the derivation of allochthonous hematite-rich sediments and dolomite

from stratigraphically higher bedrock sources upstream (likely Amsden Formation and Big Horn Dolomite). A colluvial entry of sediments into the rockshelter is probable due to the presence of a small colluvial apron along the northwestern wall of the shelter that may have extended within Big Lip Rockshelter prior to damming by sedimentation within and above the shelter.

Within Unit II, the fine-textured sedimentary units exhibit a higher degree of sorting than that represented by the matrix supported gravel units, perhaps indicating inundation of the shelter by Wyoming Creek. It seems likely that some sort of mass movement, either down the valley or from adjacent slopes is responsible for the poorly sorted, matrix-supported units. Due to the limited exposure of the strata it is impossible to make any more explicit interpretations.

In all likelihood, though this is difficult to demonstrate at present, the sediments are part of an overall late-Pleistocene/early Holocene aggradation of the alluvial fan up valley. Projection of the fan surface down to Big Lip Rockshelter (map missing), places the fan somewhere above the elevation of the modern brow of the shelter. In the immediate vicinity of the site, the narrow neck in the valley may have acted to clog sediment behind, leading to the clogging of the shelter with alluvium. This interpretation would involve substantial removal of sediment from the shelter and the lower portions of Wyoming Creek sometime after the deposition of upper strata in Unit II.

Reconstruction of Environment during Unit II times

Based on the sedimentological characteristics of Unit II, the following scenario for the evolution of the Wyoming Creek drainage is put forward for further testing and evaluation. The salient features of this argument involve the coarser texture of sediments in Unit II and the exposed alluvial fan compared to those currently transported by Wyoming Creek, and the evidence for truncation of the alluvial fan and removal of sediment from the downstream portions of the valley.

Clearly, there must have been greater movement of sediment containing larger clasts (boulders to sand) down the Wyoming Creek valley in the past. This could have been brought about by at least two different possibilities or combinations thereof.

1) The Wyoming Creek valley was previously less well-vegetated, with far greater slope angles, at least locally. This could result from the lowering of the tree line on the eastern flanks of Big Pryor Mountain and operation of an active nivation hollow in the headwaters of the stream. Greater spring runoff and runoff following rainstorms would result in increased rates of erosion of the slopes, greater velocity of Wyoming Creek, and transportation of larger clasts. This reconstruction would also result in a higher frequency of mass movements on the slopes and down this narrow valley, accounting for the matrix-supported, poorly-sorted gravels both within the rockshelter and exposed in roadcuts on the truncated alluvial fan (note, however, that the sediment in the rockshelter is far coarser than in the roadcut).

2) Alternatively, greater precipitation during Unit II time might have the same effect. The modern extensive forest cover probably precludes significant mass wasting and high energy streamflow events. In the absence of a decreased vegetative cover, it is unlikely that increased precipitation would result in the aggradation of the alluvial fan and occurrence of extensive mass wasting.

The subsequent truncation of the fan and downcutting by Wyoming Creek can then be explained by forestation of the hillslopes of the drainage basin. This would have resulted in less rapid runoff into the stream and a decreased sediment load, favoring erosion of the high-gradient surface of the fan. Removal of sediment from the narrow neck in the valley, choking Wyoming Creek at this point, would also have lowered this temporary base level, favoring downcutting to the limestone surface exposed at the confluence of Wyoming Creek and Crooked Creek.

The age of the Unit II sediments is speculative, although the available radiocarbon dates suggest an early Holocene to late Pleistocene age. The suggestion of decreased forest cover, possibly associated with increased precipitation, fits well with the evidence from the Big Horn Mountains (Burkhardt 1976), the Big Horn Basin (Chomko 1978, Gilbert et al. 1978), and Yellowstone Park, where indication of a forested environment is not found until sometime after 10,000 yr BP, during the early Holocene. Allowing time for downcutting of the alluvial fan in the valley, and erosion of sediments from within the cave down to the upper surface of Unit IIa, a date of ca. 7560 BP for sedimentation of Unit Ic fits well. In order to further evaluate this hypothesis, it will be necessary to resurvey the alluvial fan surface and attempt to recover datable materials from the sediments.

Unit I Sediments

Unit I sediments span approximately the last 8000 years of sedimentation at Big Lip Rockshelter, with no evidence of unconformable relationships within the unit. With the onset of Unit I, external sources of sediment apparently declined in significance and a combination of mechanical disaggregation from the ceiling and organic matter accumulation takes priority. At this point the lip mound probably developed as a prominent feature at the site, at the same time strongly influencing the nature of the sediment that accumulated.

The great accumulation of relatively large ($M_z=6.55$ cm) predominantly subangular to angular clasts in Unit I with only minor fine fraction, argues for rapid mechanical breakdown acting on the massively jointed bedrock forming the ceiling of the shelter. This mechanical breakdown may have occurred due to frost wedging in addition to crystal growth of secondary carbonates in the bedrock. The greater presence of secondary carbonates in Unit Ia may also indicate the origin of some of these clasts from the cliff face above the shelter which would logically receive greater amounts of moisture.

It is necessary to evaluate the role of the lip mound in influencing the pattern of sedimentation within the shelter. The position of the lip mound is such that it receives clasts not only from the ceiling of the shelter, but also from the cliff face above the shelter. Thus sediment will accumulate faster here simply because of position alone. Direct sunlight on the cliff face and greater warming of the ceiling area adjacent to the entrance should enhance the rate of freeze-thaw weathering in the brow area of the cave. Both factors account for the accumulation of rubble rising above the surrounding floor of the shelter. The presence of the lip mound then forces the bulk of sediment that normally would fall outside the shelter to accumulate within it. Therefore, the coarseness of the rubble in at least the surface unit can more readily be interpreted in light of the changing morphology of the shelter rather than in terms of temperature and/or humidity. An attempt to infer past climate on the basis of coarseness of the clasts is therefore precluded.

Site Formation

In the absence of information to the contrary, it is most reasonable to assume that Unit II was deposited sometime during either the late Pleistocene or early Holocene given the date of ca. 7560 yr BP from the base of Unit I. The shelter must have already existed at least as a shallow overhang (an earlier shelter fill may have existed that was later eroded). The now inactive and vegetated nivation hollows on Big Pryor Mountain suggest that there was more active slope movement up valley from the shelter, with intense physical weathering in the past. The neck in the hourglass-shaped valley would have acted to dam sediment behind the constriction (precisely where Big Lip Rockshelter is located). Erosional terraces indicate late Pleistocene/early Holocene erosion behind the neck of the valley, which removed an unknown quantity of sediment that may have formerly covered the floor of the shelter.

Subsequent sedimentation during Unit I time was composed entirely of products of local mechanical disaggregation of shelter walls and ceiling and organic matter from use of the site by rodents for nesting purposes. By this time, accumulation of sediment within the

shelter, and incision of the small stream in Wyoming Creek, acted to place Big Lip Rockshelter beyond the effects of fluvial introduction of further sediment.

Discussion

For much of its existence this site evidently received sediment from sources exterior to the cave. Following stabilization of the slopes of the Wyoming Creek valley, and removal of sediment choking the shelter, autochthonous production of coarse clast sediment became the dominant sediment source, rapidly constructing the modern lip mound that gave the shelter its name.

The sediments in Unit I at Big Lip Rockshelter, in a very general sense, mirror the evidence for increased production of coarse clasts in the upper sedimentary strata at False Cougar Cave, dating to perhaps 4000-3000 yr BP. This increase in the production of coarse clasts in late Holocene sediments follows somewhat smaller percentages of the coarse fraction in the mid Holocene strata. These changes in the ratio of coarse to fine fraction in these strata may in fact relate to regional climate changes over the mid to late Holocene. For Big Lip Rockshelter, however, the possibility of the changing morphology of the shelter, especially the formation of a prominent lip mound, make any correlation to strata at False Cougar Cave unwise.

The very large mean size of clasts at this site is related to the coarse spacing of joints and bedding surfaces in the host limestone, and probably is unrelated to changes in the mechanical weathering regime at the site. Due to the dry nature of the rockshelter, it is probable that post-depositional clast reduction was relatively slow.

It is difficult to relate the presence of the secondary carbonate coatings to the dry rockshelter environment. However, particularly in the surface Unit Ia, some of the carbonate coated clasts may have originated from the more moist cliff face above the shelter. Additionally, there is no need to assume that the secondary carbonates are coeval with the evolution of the shelter. These coatings may have developed in joints or along bedding planes at any time within the history of the shelter, perhaps even before the shelter proper was excavated into the canyon wall.

CRYSTALSIN CAVE (24 CB 85)

Environment and Description

Crystalsin Cave (45°08'N/108°25'W) is located at the base of the canyon wall beneath Commissary Ridge, which forms the eastern edge of Crooked Creek Canyon at an elevation of approximately 1828 m (Figure 17). The cave is located approximately 100 m above Crooked Creek and approximately 10 m beneath the top of the canyon wall. A Douglas Fir forest lining the canyon at this point surrounds the cave. The floor space of Crystalsin cave is approximately 150 m² and the cave mouth at the drip line is 18 m wide (Figure 23). A major grotto exists at the rear of the cave. A fan-like structure emanates from the grotto indicating movement of material from this feature out onto the cave floor.

The ceiling and walls of this cave show quite a range in composition. Along the south wall there are remnants of an old breccia fill, consisting of rounded clasts that powder easily in a matrix of silt to sand-sized cemented fragments. To the north, the ceiling consists of heavily micro-jointed limestone, probably the original ceiling of the cave jointed during faulting along the Crooked Creek fault zone. These differences in lithology have great significance for production of coarse and fine sediment fractions. The old breccia fill weathers easily through grain by grain erosion, apparently occasionally releasing whole rounded clasts contained within the breccia. The jointed bedrock surface also weathers quite easily, but by expansion of either calcite or water on freezing in the joint spaces. Hammer blows quite easily dislodged several handfulls of angular clasts from the jointed section. The interior surfaces of the clasts were heavily coated with secondary CaCO₃,

implying that the precipitation of calcite in the joints exerts a crystallization pressure sufficient to dislodge clasts. The bedrock is bisected by two major joints located on the rear wall of the cave. Rooffall blocks, perhaps originating from larger scale jointing, litter the southern floor of the shelter.

The sediments at Crystalsin Cave are extremely complex, exhibiting considerable lateral variation over short distances in the excavated areas. The bulk of the sediments, in the upper strata at least, consist of varying amounts of limestone rubble, breccia fragments, calcite crystals, and silt. These sediments are the products of mechanical weathering of the cave walls and ceilings. The cave is quite dry during the summer except for water dripping from fissures in the grotto at the rear. It is likely that the amount of water discharge from these fissures following the spring snow melt is considerably greater, though this process was not observed.

A further sediment source may be the small fan at the north margin of the cave. These sediments are most probably derived from the red siltstones and shales of the Amsden Formation which crops out on Commissary Ridge above the cave. The reddish tint imparted to sediments containing appreciable amounts of this material makes it easy to distinguish in section. This visual clue was not found in the sediments within the cave. It appears likely that a bedrock arm at the north margin of the cave has precluded their introduction beyond the dripline. These sediments have, however, had a marked influence on excavated deposits outside the dripline. In the trench outside the cavern, the upper sediments are stained reddish, suggesting introduction of hematite-rich silts from above the cave. Beneath these reddish stained sediments, the deposits are similar to those within the cave suggesting that they were beneath the cave brow at the time of deposition.

Modern introduction of appreciable quantities of aeolian sediment appears unlikely. Wind activity inside the cave was light, even when gusting fairly briskly outside, and it was only out on the dripline that dust from excavation was redistributed to any great extent. The present forest cover directly in front of the cave mouth retards modern wind velocities, but reduced forest cover in the past may have allowed for more vigorous wind activity.

Physical Stratigraphy

The physical stratigraphy of Crystalsin Cave is here divided into five lithostratigraphic units. Descriptions of individual units are presented in Table 8. The lower stratigraphic units, III-V were only accessible for study over one afternoon. The remainder of the time they were boarded up. Due to the incomplete study of these lower sediments, they will be discussed only cursorily.

Age and Rate of Sedimentation

The four C^{14} dates processed from Crystalsin Cave are plotted on Figure 24. The date of 4020 ± 90 yr BP provides a mid to late Holocene estimate for the beginning of sedimentation in the uppermost portion of Unit II and the overlying Unit I. Lack of further organic materials or paleontological remains makes it impossible to estimate the age of earlier strata.

Curves for the estimated rate of sedimentation, based on the depth below surface of C^{14} samples, are plotted in Figure 25. These curves suggest that there has been a variable rate of sedimentation over the last 4000 years, with a greater rate of sedimentation (34 cm 1000⁻¹ years) from the base of Unit I to the surface. Based on a date near the surface of Unit I, the rate of sedimentation apparently decreased in the uppermost levels of the sediment column.

Extension of the average sedimentation rate of 17 cm 1000⁻¹ years to underlying strata is ill-advised for Crystalsin Cave. The evidence for rapid roof collapse in these strata would suggest a more rapid rate than that evidenced for overlying strata. Further, the steep dip of strata out of the cave make it likely that considerable removal of sediment occurred throughout the period of time represented by sediments in Unit V-II.

Sediment Sampling

Three sediment sampling columns (1, 2, 3) were utilized (positions located on Figure 24) forming a transect from the entrance to the interior. In column 1, samples were taken from each lithostratigraphic unit, as considerable variety in sediment composition exists within this area. In columns 2 and 3, sediment samples were taken approximately every 5 cm due to the textural homogeneity of the sediments in this area of the cave.

The Unit I sediments exposed in the extreme western portion of the profile were uncovered only long enough to be mapped and described. While the author was away, visiting other sites, this excavation unit was backfilled and therefore no sediment samples were taken.

Description of the Lithostratigraphic Units

Unit I

The sediments making up Unit I comprise a series of strata consisting of coarse limestone gravels alternating with levels composed of silt and less numerous limestone clasts. The sequence of alternating coarse and fine units is best expressed on the north wall profile illustrated in Figure 24. Considerable lateral variation exists for this unit. Eastward along the north wall profile, the gravel strata pinch out, and are only expressed as intermittent gravel lenses with sporadic charcoal inclusions.

Tracing Unit I westward proved more difficult as the intervening sediments had been removed during previous excavations. On the west wall profile, Unit I is represented by a single, homogeneous unit consisting of a limestone gravel supported by a silt-rich matrix. Evidently, the intervening levels of fine sediment pinched out near the entrance to the cave.

During the 1982 field season, portions of the north wall profile were removed showing that the alternating coarse and fine units extended only a short distance to the north, and the sediments became much more homogeneous, resembling the sediments exposed along the west wall profile.

Vertical separation of Unit I subunits is also unclear towards the north and south along the north/south transect. To the north, Unit I consists of a single, relatively homogeneous gravel and silt to where it intersects a bedrock arm extending out from the wall of the cave. Towards the southern end of the trench, beyond the large boulder illustrated on the section profile, Unit I consists of a thick, clast-supported limestone gravel, capped by a layer of silt with rare gravel-sized clast inclusions.

The southern, and eastern walls of the 4 x 4 m unit excavated at the southern area of the cave are illustrated in Figure 26. On the western wall Unit I consists of two relatively coarse gravel units separated by a single silt unit. The lower coarse stratum consists of large (5-10 cm diameter) limestone and breccia clasts with very little silt matrix filling the voids. On the southern wall, Unit I consists of a surface silt layer overlying 3 strata consisting of variable amounts of clasts to matrix. On the east wall, a silt stratum separates units of coarse gravel which are in several instances, lenses of pure gravel. Overlying these strata are a series of finer strata.

Figures 27-29 illustrate the changing contribution of the three size fractions to the global granulometry of each sample. In general, the gravel fraction (>1 cm) decreases away from the cave entrance towards the interior. In sample column 3, fine fraction sediments comprise the bulk of every sample. A decrease in the mean size of clasts occurs from Sample column 1 to 2, where sufficient A fraction clasts exist.

Coarse fraction clast angularity in sample column 1 increases from basal Unit I towards the surface. Rounded and subrounded clasts form a significant portion of the sample only in the lower units. Secondary carbonate concretions additionally increase to a maximum in the surface of Unit I, though there exists a significant percentage of concretions on the clasts in the lower Unit I.

Contrary to the increase in coarseness of the A fraction towards the cave interior, the sand portion of the fine fraction generally decreases towards the cave interior with silt and clay size fractions decreasing in importance. The median and mean size of fine fraction sediments similarly decreases towards the cave interior. All sediment samples were uniformly very poorly or extremely very poorly sorted. The organic matter content of sediments generally decreases downsection as well as from the cave entrance towards the interior.

Cultural units 1, 2, 3 and 3a are contained within Unit I. Between E8 and E9 on the north wall profile of the east/west transect, these cultural units are clearly separated stratigraphically. The cultural units are contained within the coarse gravel strata which are separated by intervening silt strata. The cultural units can be traced eastward as charcoal flecks within the thin gravel lenses described previously. On the remaining profiles the delineation of distinct cultural levels is less clear. On the west wall profile C-3 is likely represented by the dashed line at the base of Unit I (Figure 25). Scattered charcoal was evident within this area and its stratigraphic position makes it likely that it correlates with C-3 on the North wall profile. Above this somewhat unclear charcoal zone, C-2 is presumably represented by bone fragments midway down Unit I.

The explanation for the observed trends in the grain size parameters both vertically and horizontally within the section are speculative, but likely relate to the variable nature of the ceiling rock and human activity. The upsection increase in angularity and carbonate concretions is most readily explained by the progressive removal of the breccia fill and subsequent exposure of more crystalline, though highly jointed limestone. The breccia fill is highly porous, and crumbles easily, making it both difficult to produce angular fragments and precluding significant buildup of carbonate concretions on clast outer surfaces.

A similar explanation may largely account for the decrease in A fraction clasts towards the cave interior. A further explanation may be the presumably drier environment of the cave interior, and lesser exposure to direct solar radiation, slowing the rate of mechanical weathering in the cave interior.

Interunit variation within Unit I may relate to human cultural activities. Living surfaces may have been disturbed, winnowing out the finer fractions and exposing the coarser fractions at the surface. Due to the localized nature of these gravel concentrations, a climatic explanation is not warranted.

It is unclear to me why the fine fraction should increase in coarseness towards the cave interior. Perhaps this trend relates to very low velocity overland flow of water from the cave grotto at the rear of the cave. Thus, the finer fraction may have been selectively winnowed in the rear of the cave and deposited nearer the cave entrance, in the vicinity of sample column 1.

Unit II

Throughout the area in which it is exposed, Unit II exhibits a smooth, distinct contact with Unit I. Within Unit II, the limestone and breccia clast content decreases and there is a slight increase in the clay-sized fraction. The slope gradient of the surface of Unit II is similar though steeper in some areas than that of overlying Unit I. The lower boundary of Unit II slopes steeply out towards the mouth of the cave, mirroring the attitude of lower sedimentary units. It would appear that the sediment surface at Crystalsin began to level out at some point within Unit II, during the mid Holocene.

Evidence of cultural activity in Unit II is present in the form of a distinct charcoal lens underlain by an area of reddened earth bisected by the east/west transect and an area of scattered charcoal and limestone clasts in similar stratigraphic position on the west wall.

Unit III

Unit III is exposed in only a portion of the east/west transect. In the 1 x 2 m unit excavated between E7 and E9, Unit III consists primarily of masses of calcite crystals in rosettes, and loose, large rooffall blocks fractured by excavation activities. An unconformity exists between Unit II and III with a very steep gradient going down from east to west. The surface of Unit III is stained pink and yellow. No cultural material was recovered from Unit III or subsequent units.

Genesis and Diagenesis of the Sediments

The lower stratigraphic units represent sedimentation and erosion under conditions different from those of upper Unit I. These lower units lack appreciable amounts of limestone clasts in general, with the coarse-fraction of the deposit consisting primarily of calcite crystal fragments and breccia detached from the wall. In the very lowest deposits exposed, blocks of breccia are strongly imbricated, dipping steeply toward the southwest.

The remaining lower units (III and IV) also display a strong dip towards the mouth of the cave. None of the lower units extend all the way to the rear of the cave, at least in the section exposed by the east/west transect. Presumably these relationships indicate periods of erosion and removal of sediment from a possible bedrock shelf at the rear of the cave.

The origin of the calcite crystals in Unit III is most likely a result of their collapse from pockets of calcite crystals still evident in the ceiling and from whence the cave takes its name. Likely their abundance here, as well as the presence of abundant rooffall blocks implies a local tectonic event that caused significant collapse of large ceiling blocks. Alternatively, or perhaps in conjunction, roof collapse may relate to removal of support for the relatively weak breccia fill by excavation of the cave.

Unit II presents the earliest evidence of human utilization of the cave. The sediments here still lack appreciable amounts of limestone gravel, but the deposit gives no indication of being extensively eroded prior to the deposition of Unit I.

Unit I differs in sedimentary content from all other units. Although extremely variable in character, it is distinguished by relatively greater amounts of coarse gravel with intervening strata of fine silt. The gradual increase in coarseness of clasts toward the mouth of the cave fits a model of cave microclimatology in which the influence of the exterior climate is felt most strongly near the cave entrance. In addition, the increasing coarseness of the clasts from north to south within the cave mirrors the increasingly fractured state of the ceiling rock in this direction.

The explanation for the alternating levels of coarse and fine strata is most likely the result of cultural activity. Cultural material is largely restricted to the coarser units.

Site History

Due to only limited exposure of the lower sediment accumulations, the evolution of Crystalsin Cave is poorly understood. In addition, the lack of dates for the bulk of the section precludes accurate historical reconstruction.

Crystalsin Cave was largely formed by mechanical weathering of an ancient breccia-filled cavern exposed by faulting along Crooked Creek and retreat of the cliff-face. The less resistant breccia-filled cavern must have eroded rapidly relative to the surrounding cliff-face, producing a small reentrant. Subsequent weathering removed the breccia fill from all but the southern walls of the shelter where it is still being removed at the present time.

The original slope of the interior of the expanding cave must have been steep and is represented by the large imbricate blocks on the old cavern floor exposed in Unit V. Subsequent sediment was primarily in the form of loose, powdery breccia fill and occasional gravel-sized fragments. As the ceiling of the cave was gradually weathered, pockets filled with calcite crystals were intersected from which the cave gets its name. These crystals make up a large proportion of some of the lower units.

By the end of Unit IV time, the floor of the cavern was approaching a horizontal orientation. Subsequent sedimentation has involved the production of clastic sediment from the ceiling and introduction of small amounts of organic material from the exterior.

DISCUSSION OF THE MID-ELEVATION SITES

At both Crystalsin Cave and Big Lip Rockshelter, the primary factors contributing to variability in the sedimentary strata have to do more with bedrock lithology and structure, and the geomorphic evolution of the sites, than their climatic history. Big Lip Rockshelter, positioned near the canyon floor, received fluvial and colluvial sediments throughout the early part of its history. Subsequent accumulation of physically weathered clasts was strongly controlled by the wide joint spacing of the ceiling and walls and the development of a prominent lip mound. At Crystalsin Cave, weathering and erosion of the original breccia fill determined the character of the lower sedimentary units. Variation within the upper sedimentary units was controlled to a large degree by whether a portion of the cave floor lay beneath the loose breccia ceiling or by the finely jointed crystalline bedrock ceiling.

The coarse fraction of the upper strata at Big Lip Rockshelter comprised a greater proportion of samples than at Crystalsin Cave, with values of between 60 and 80% for the A fraction, compared to values ranging between 10% and 70% at Crystalsin Cave. It is further believed that the coarseness of some samples from Crystalsin Cave may be due to post-depositional mixing by human and/or animal occupants of the cave.

The roundness of clasts from Big Lip Rockshelter is also greater than values from Crystalsin Cave. At Crystalsin Cave a significant proportion of clasts were angular, compared with lower values from Big Lip Rockshelter. Carbonate concretions, present on clasts from both sites make up a greater proportion of the clasts at Crystalsin Cave.

Organic matter values also differ significantly between the two sites. The upper strata at Big Lip Rockshelter are much more enriched in organic matter than strata at Crystalsin Cave. This fact obviously relates to the less open nature of Big Lip Rockshelter, making it more attractive to rodents than Crystalsin Cave.

The reasons behind the textural and morphological differences exhibited at Big Lip and Crystalsin are most readily attributed to differences in bedrock lithology and structure, mentioned earlier, and differential moisture levels between the two caves. Crystalsin Cave is a drier cave. Big Lip Rockshelter, being of smaller size and situated on the valley floor, must receive greater drifting snow than Crystalsin Cave, situated at the top of a steeply-sloping colluvial slope. Additionally, the increased organic fraction at Big Lip Rockshelter, in conjunction with lower porosity of the sediments must act to elevate effective moisture levels above those present at Crystalsin Cave. Therefore increased snow drifting and moisture retention argue for greater post-depositional chemical weathering of sediments in Big Lip Rockshelter.

The higher frequency of secondary carbonate concretions at Crystalsin Cave argues that, although the cave environment is drier, a significant volume of carbonate rich groundwater must percolate through the ceiling rock from the surface. However, the extensive fracturing of the ceiling rock makes it possible that formation of the secondary carbonate concretions may have occurred long before the clasts were actually detached.

LOW ALTITUDE SITES

Two sites were examined on the southwestern slopes of the Pryor Mountains. Both are shallow rockshelters, formed by the differential weathering of cross-bedded units within the local Pennsylvanian Tensleep Sandstone exposed at lower elevations adjacent to the Big Horn Basin. "Beyond Level Rockshelter" contained both a cultural record spanning the late Holocene, and a paleontological record that apparently extends back into the late Pleistocene. "Shallow Promise Rockshelter" contained a small paleontological record and no cultural materials.

While it would have been more useful to examine caves or rockshelters formed in carbonate strata, no suitable sites were excavated as a part of the Pryor Mountain Fieldschool. Most such sites were located on the Crow Indian Reserve and could not be investigated.

ENVIRONMENT AND CLIMATE

The two sites described here occur at the base of Big Pryor Mountain where the moderately dipping Paleozoic strata extend beneath Tertiary strata and unconsolidated Quaternary alluvial sediments of the Big Horn Basin (Figure 30). In this area, the upper Pennsylvanian Tensleep sandstone has been dissected into a series of moderately dipping flat-irons, with shallow steep-sided, though canyons dividing them. The vegetation is a typical xerophytic cover consisting of juniper (*Juniperus osteosperma*) and sagebrush (*Artemisia arbuscula* var. *nova*). Precipitation averages between 159-264 mm annually, with a mean annual soil temperature between 5.5° to 6.6° C. The frost free season varies between 70 and 85 days (South 1980).

SHALLOW PROMISE ROCKSHELTER

Shallow Promise Rockshelter (45°06'N/108°36'W) is a shallow rockshelter at approximately 1501 m elevation, eroded into a small overhang in the Tensleep Sandstone. Weathering of sand off the cliff has produced a small accumulation of colluvial sand which extends into the site. The mouth of the site is oriented towards the SE.

Shallow Promise was excavated by a small crew during the summer of 1982. No cultural materials and little in the way of paleontological remains were recovered during the excavations. Thus this site provides an opportunity to compare sedimentation uninfluenced by human or other biological agencies.

Physical Stratigraphy

The lithostratigraphy of Shallow Promise was fairly homogeneous throughout with the exception of lower portions of the section which were somewhat enriched in secondary CaCO_3 . Thus in the field I divided the section into two units (I and II) on the basis of carbonate enrichment (Figure 31). There was also a small pocket of coarse rubble at one end of the section extending out from beneath the shelter brow.

Characteristics of the Sediment

Figure 32 presents the sedimentological data for Shallow Promise Rockshelter. The sampled bedrock consists of a moderately sorted (.71 ϕ), strongly coarse-skewed, platykurtic sandstone. Samples taken from the sediments at Shallow Promise differ most significantly from the original bedrock in the presence of a small clay fraction and significant quantities of silt. Additionally, there is considerable variation from the original bedrock in the sorting, skewness, and kurtosis of samples.

The uppermost sample, from near the surface in Shallow Promise most closely resembles the bedrock sample in terms of sorting (σ_1) and shape of the particle size distribution (skewness and kurtosis). For these parameters, the lower samples all deviate

significantly, being much more poorly sorted ($\sigma_1=1.89\phi-2.41\phi$ vs. $<1\phi$), positively skewed (+39-+51, i.e. tail of fines) and leptokurtic (5.40-8.90, i.e. strongly peaked).

In order to view the relationship between increasing mean size of the fine fraction and other grain size parameters, scattergrams were plotted and correlation coefficients were calculated for these variables (Figure 33). All three variables show a strong positive correlation to mean size ($r = >.900$). These diagrams show that as the mean size of clasts in the fine fraction increases, there is a corresponding decrease in sorting (i.e. more poorly sorted), in skewness (i.e. a progressively greater tail of fines) and kurtosis (i.e. frequency distribution becomes progressively more peaked). If we assume that the bedrock sample represents the initial sediment weathered off the rockshelter walls and ceiling, we can compare differences in samples and interpret the differences in terms of other depositional processes or post-depositional alterations.

If the bedrock sample grain size characteristics represent the initial sediment, any process which introduced additional fine material ($>4\phi$) would result in samples being more highly positively skewed, more leptokurtic, and more poorly sorted, as is evident in all the sediment samples except for the sample taken from near the surface. I believe then, that it is reasonable to infer that the four lower samples received sediment not only from the rockshelter, by removal of grains off the walls and ceiling, but also accompanied by the simultaneous introduction of varying amounts of additional fine sediment.

The presence of a significant silt fraction and a minor clay fraction are most reasonably interpreted as a result of introduction by animal tracking, feeding, and defecating as well as local aeolian importation. It is difficult to envision these fractions entering strictly by biological agencies for several reasons. There is a near total lack of organic matter or paleontological remains in the deposits, providing little evidence for use of this shelter by animals. There is additionally little silt or clay-sized material in the vicinity of the shelter to serve as a source for such sediment tracking by animals. For these reasons, and given the exposed position of Shallow Promise Shelter, I interpret the major source of fines to aeolian winnowing of nearby sandy sediment and subsequent deposition.

The down-section decrease in sorting may be a result of additional fine material introduced to the sediment or by the operation of various turbation processes thoroughly mixing the sediments throughout the profile. The sample near the surface resembles closely the sorting and other characteristics of the bedrock, suggesting some sort of progressive alteration of the grain size makeup of samples from lower in the column.

There exists little variation in the A-fraction of the samples, as nowhere did the gravel fraction contribute significantly to the overall accumulation. Given the lack of small-scale jointing and the apparent ease of grain-scale weathering, this is not unexpected.

Formation of the Sediment

In interpreting the origin of the sediment in Shallow Promise Rockshelter, as well as the nearby Beyond Level Rockshelter, I divided the various clast sizes into fractions that could have been introduced by various natural and cultural agencies. The coarse fraction is nowhere important at Shallow Promise Rockshelter. It would, in fact, be difficult to explain a significant coarse fraction, if it existed, because if an allochthonous introduction of coarse clasts can be ruled out (i.e. humans), then they would have to originate from simple gravity fall from the walls and ceiling of the shelter. However, weathering of the local sandstone is primarily grain by grain, with apparent mean values in the range of medium sand, and occasional clasts up to granules with a modal value of around 2.8 to 4 mm. Production of coarser clasts, greater than about 1 cm in size, seems to be a result of weathering along joints and production of roof-fall blocks that may undergo further post-depositional size reduction (see discussion for Beyond Level Rockshelter where there exists a significant coarse fraction in some samples). Their presence in significant quantities might therefore reflect an allochthonous origin, in this case, most reasonably, humans. The medium fraction, on the other hand, is probably too small to be of any

cultural use (unless it represented the breakdown of formerly large clasts) and is most reasonably interpreted as the result of local weathering and gravity fall. The finer fraction could result from either aeolian introduction or grain by grain weathering within the shelter. Given the local sparse vegetative cover and the abundance of available unconsolidated sediment of sand size, it is tempting to interpret the sediment fill within Shallow Promise Rockshelter as a result of aeolian transport of locally weathered sandstone over short distances. Given the lack of any other tools to distinguish between the two processes, it is only by comparison of the characteristics of local bedrock to those of the sediment within the shelter fill that the relative influence of the two processes can be at least qualitatively evaluated.

Discussion of Sedimentary Processes at Shallow Promise Rockshelter

It is most probable that the dominant mode of sediment accumulation within Shallow Promise Rockshelter was from weathering of the host bedrock producing dominantly sand and fine granules with intermittent aeolian and biogenic introduction of a silt and small clay fraction.

BEYOND LEVEL ROCKSHELTER

Location and Description

Beyond Level Rockshelter (45°08'N/108°26'W) was excavated by members of the Pryor Mountain field school during the summer of 1982. The cave is a small reentrant, formed by differential weathering of the Tensleep Sandstone. The cave, at an elevation of 1492 m, faces southwest in a shallow alluvium-floored canyon. The site excavation consisted of two 1 x 2 m test pits down to bedrock at a depth of approximately 2 m.

Sediments within the canyon are part of a larger alluvial surface sloping away from the Pryor Mountains towards the Big Horn Basin. The sediments comprising the alluvium are sandy silt in composition. Along the cliff face surrounding the canyon a thin, near angle of repose, colluvial apron of sandy sediment exists as a result of weathering of the sandstone bedrock. This sandy colluvial apron slopes up approximately 11 m from the canyon floor to the surface of the small cave (6.5 m deep; 6.8 m wide; 2.3 m high) named Beyond Level Rockshelter (Figure 34). The mouth of the rockshelter is oriented south 40° west.

The Tensleep sandstone consists of both massive and coarse cross-bedded sandstone. The cross-bedded units appear to weather more rapidly, as it is in these units, along major joints, that formation of the small recesses and rockshelters have occurred.

Physical Stratigraphy

Throughout most of the exposed section, the sediments consist predominantly of very poorly to moderately poorly sorted, medium to coarse sands to silty sands. Sandstone clasts between 10 cm and 2 mm make up a significant proportion of the sediment in only a few samples. Largely undegraded organic matter in the form of cactus needles, twigs, and leaves was present only in the upper part of the section. Sections of the profile were enriched in pedogenic CaCO_3 .

The section was subdivided into six stratigraphic units in the field (Figure 35). Descriptions of these units are contained within Table 10. The upper four units contain greater quantities of organic-matter and large clasts. Unit 5 is a massive, homogeneous unit of sand with few large clasts and no evidence of organic matter accumulation. The lowermost portion of the section, still devoid of organic matter, yields slightly greater numbers of clasts between 10 cm and 2 mm than does the overlying unit 5.

Characteristics of the Sediment

Most of the section consists of silty-sand with very minor coarse fraction greater than 1 cm in diameter (Figure 36). Only in the upper portions of the section is there a significant coarse fraction. The medium fraction is virtually absent in several samples, and obtains relatively large values only in samples 13 and 12 within Unit III. Due to the relatively small size of the coarse fraction, and the impossibility of obtaining sufficiently large samples of sediment representative of size variation within the coarse fraction, a more detailed analysis of this fraction was not attempted.

Sand values are fairly constant throughout the section, reaching relatively high values in a few samples in the upper part of the section (15 and 13) where it accounts for more than 70% of the fine fraction. The silt fraction everywhere constitutes at least 20% of samples with a great deal of variation throughout the section. The mean size of the fine fraction varies between approximately 3.5 ϕ and 4.5 ϕ (coarse silt to fine sand). The fine fraction was very poorly to poorly sorted except for one sample within Unit V that was moderately sorted. All samples were fine to strongly fine skewed and very to extremely leptokurtic.

Organic matter values decrease downward with only slight interruptions from a maximum in the surface unit. As this value is not associated with evidence for increased human occupation and decreases with depth, I ascribe the decreased values in lower strata to time dependent decay of organic matter.

In general, the kurtosis and sorting decreases systematically (i.e. becomes more leptokurtic and more poorly sorted) with a decrease in mean sediment size (Figure 37). Such a strong correlation is not evident between skewness and mean size. This correlation between mean size, sorting, and kurtosis was also found at Shallow Promise Rockshelter, shifting values away from those present in the host bedrock. I believe the explanation is similar at both sites; i.e. variable input of finer (silt and clay-sized) clasts by aeolian action from outside the rockshelter.

Formation of the Sediment

If we employ the same reasoning concerning clast size variation of possible depositional agencies as with Shallow Promise Rockshelter, sedimentation in Beyond Level appears to have been a combination of two primary processes. For most of the shelter's existence, represented by the lower stratigraphic units, sedimentation was achieved primarily by gravity fall of weathered sand and silt grains from the bedrock walls and ceilings with the addition of an undeterminable component of aeolian sediment. In the upper portion of the section, a combination of the former processes with the introduction of foreign materials by animals and humans was in evidence. In addition, the accumulation of a significant coarse and medium fraction occurred in the upper parts of the section. As this part of the section also contained relatively abundant cultural remains, it is tempting to correlate the two. Certainly, humans played at least some role in the introduction of the coarse fraction because infrequent exotic pebbles of black chert were associated with these levels. It is also reasonable to suppose that humans imported local sandstone clasts as part of their activities at the site (perhaps in grinding activities or as hammerstones, though the former activity would produce a great deal of grit). If we compare the upper part of the section to the lower parts, and to the sediment seen earlier from Shallow Promise Rockshelter (both of which presumably represent non-anthropogenic sediments), the presence of a large coarse fraction is striking. In addition, examination of other recesses in the Ten Sleep Sandstone, suggests that the production of relatively coarse clasts is rare. The production of coarse clasts seems to be associated with relatively large roofblock collapse, such as represented by the large boulders, partly covered in sediment within Beyond Level Rockshelter. Without other evidence to the contrary, I suggest that the coarse fraction in the upper part of the section is primarily a result of roof collapse and as yet unknown human activity.

Modern evidence suggests that weathering proceeded along major grain-size differences in individual cross-bedded units. The ceiling and walls of the shelter today consist of friable, partly detached exfoliation leaves that apparently correspond to individual cross-beds. Thus detachment is a mixture both of grain by grain disintegration and dislodgement of very thin sheets of still partly cemented cross-beds (see discussion at end of this chapter).

PHYSICAL WEATHERING PROCESSES IN LOWER ELEVATION SITES

Accumulation of the sedimentary fills in both Shallow Promise and Beyond Level Rockshelters was likely a result largely of internal weathering of the walls and ceilings of the shelters. Aeolian introduction of sediment was apparently a minor process. Anthropogenic and biogenic introduction of sedimentary materials and turbation of the primary sediments was, particularly for the upper stratigraphic units at Beyond Level Rockshelter, a dominant factor.

Production of the clastic sediment in the rockshelters must have been a result of processes other than simple freeze-thaw disaggregation of the host sandstone. Although presumably the bedrock surfaces are subjected to significant temperature variations through the yearly cycle, both in terms of absolute temperature and probable oscillations around the 0° isotherm, low moisture levels, particularly in conjunction with rock temperatures below 0° C (see Thorn 1979, 1980, Hallet 1983) would mitigate against significant rock disintegration by freeze-thaw weathering (more abundant moisture during spring melting would not be associated with depressed temperatures).

Granular disintegration of the carbonate-cemented sandstone by salt crystallization (Evans 1970, Chapman 1980, Smith and McGreevey 1983, Watts 1983), either alone or in conjunction with hydration is, on the other hand a more viable explanation. The modern ceilings and walls of the shelters were characterized by uneven, loose, granular surfaces with patches of a whitish crystalline substance associated with thin exfoliation leaves apparently paralleling cross-bedding surfaces. The whitish crystalline substance is evidently precipitated salt (probably gypsum). This pattern of disintegration matches very closely that described by Chapman (1980) for sandstones in Saudi Arabia and the experimental evidence cited above.

If the above process is in fact the dominant one involved in the formation and infilling of the shelters, it would explain the apparent uniformity in textural characteristics of the lithostratigraphic units; the salt crystallization hypothesis would operate as long as saturated solutions were brought to the bedrock surface and evaporation of the solution proceeded under a relatively arid climate. In order to confirm or reject this hypothesis, a more detailed study of sandstone disintegration along exposed canyon walls would be necessary, including geochemical analysis of the salt efflorescences.

DISCUSSION OF PRYOR MOUNTAIN STUDY SITES

The Pryor Mountain study sites provide us with the opportunity to examine changes in the pattern of clastic sedimentation with decreased mean temperature and shorter frost-free periods as a function of increased altitude. To a certain extent, the bedrock variable is held constant, for at least the mid and upper elevation sites. However, local variations in host rock characteristics, geomorphic position, and microclimate have produced variations in the character of the sediments that far exceed those due to regional climatic change.

The range of mean size of coarse fraction clasts and the range of percentage values for the coarse fraction of sediment samples from the four mid and upper elevation sites are plotted in Figure 38. It is clear from the diagram of coarse fraction percentages that there exists no simple, clear increase in the overall coarseness of sediments at higher elevations. The mid elevation sites produce some of the coarsest samples, both from Crystalsin Cave

and from Big Lip Rockshelter, and at Crystalsin Cave samples containing a very small percentage of coarse clasts were also noted. The two upper elevation sites differ dramatically, with False Cougar Cave exhibiting approximately medial values for coarseness, and Cave Ann producing the least coarse textured samples of all the mid and upper elevation Pryor Mountain sites.

Due to extremely small samples from Cave Ann, it was not possible to calculate values for this site. The remaining three sites exhibit similar maximum mean size values for certain samples, although the majority of samples from Crystalsin Cave have lower mean sizes than those from Big Lip Rockshelter and False Cougar Cave. The two samples from Big Lip Rockshelter, from a less rigorous local climate than is present at False Cougar Cave, have similar, large mean sizes of coarse fraction clasts.

False Cougar Cave exhibits the highest rounding index values while Crystalsin Cave, on the whole, contains higher numbers of angular and subangular clasts. The single high rounding index value from Crystalsin Cave may be attributed to higher frequencies of rounded breccia fragments in that strata.

As discussed in previous sections, the reasons for the disparity in values of mean size and percentage of coarse fraction clasts, and rounding index values can be related to factors intrinsic to the local bedrock, orientation and openness of the sites, and microclimatic variability in sites of similar elevation. At Big Lip Rockshelter and Crystalsin Cave it appears that the size and spacing of joints and bedding planes strongly influenced the size of mechanically disaggregated clasts, resulting in clasts of relatively large size at Big Lip Rockshelter and smaller clasts at Crystalsin Cave. Both False Cougar Cave and Big Lip Rockshelter are also "wet" sites, a condition that in all likelihood accelerated the rate of coarse clast production (by whatever physical weathering process). Cave Ann, being a relatively dry site, experienced significantly less mechanical disaggregation. Crystalsin Cave, though relatively dry as well, experienced somewhat higher rates of clast dislodgement due to the highly fractured state of most of the ceiling rock, and perhaps the influence of calcite crystal growth in joints. The wetness of the cave environments of False Cougar Cave and Big Lip Rockshelter, in combination with high organic matter content that promotes moisture retention, accounts for the greater occurrence of pre- and post-depositional rounding of clasts at these sites.

In order to compare the increase in mean size of clasts with increased coarseness of samples, scatterplots were prepared illustrating the relationship of these two variables and correlation coefficients were calculated where sufficient sample size exists. The results are presented in Figure 39. A weak to relatively strong (Crystalsin Cave) correlation appears to exist between the mean size and percentage contribution of the coarse fraction at these sites. The correlation does not appear to be strong enough to suggest that values for one variable could be reliably predicted from values of the dependent variable.

It is not clear what a strong correlation between mean size and coarse fraction percentages indicates. Laville et al. (1980) might argue that as the climate becomes more rigorous (greater intensity and lower frequency of freeze-thaw events) relatively larger clasts are dislodged and there is a lower rate of production of finer, sand and silt-sized, sediment. However, a strong correlation between these two variables could indicate that, beginning with samples composed of equivalent mean size and percentage coarse fraction, the sample undergoing greater secondary frost weathering would experience post-depositional clast size reduction, simultaneously reducing the quantity and size of coarse fraction clasts. Certainly if some property of the host rock (such as joint spacing in the case of Crystalsin Cave) is controlling the size of the primary clasts, there should be no reason to expect a significant correlation between mean size and coarse fraction percentage. However, Crystalsin Cave exhibits a higher correlation coefficient than False Cougar Cave. A tentative suggestion might be that as the percentage of the coarse fraction decreases, by definition meaning an increase in the finer fraction, the greater fine matrix acts to hold in moisture, promoting post-depositional clast reduction processes.

At all sites allochthonous elements dominate over autochthonous ones for much of the sediment accumulation. Allochthonous fine fraction sediments were introduced in large quantities by biological agencies, with the subsequent effects on post-depositional alteration of coarser clasts. At Big Lip Rockshelter and False Cougar Cave, the sediments comprising the lower sedimentary units were in whole or in part derived from sources exterior to the cave. Failure to take into account both biological agencies and the syn-depositional geomorphic position of these sites would have precluded an accurate interpretation of the genesis of their sediments.

The lower elevation sites are not strictly comparable to the other Pryor Mountain sites due to extreme differences in the bedrock in which they formed. It is interesting to speculate on the nature of the sediments at these sites had they formed in limestone similar to that at the other sites. As far as I am aware, no one has documented the mechanical disaggregation of limestones in arid regions by salt crystallization, similar to that reported here and elsewhere (e.g. Cooke 1981, Cooke and Smalley 1968, Goudie et al. 1979) for sandstones. Due to the very different nature of groundwater transport in crystalline carbonate rocks as opposed to the intergranular porosity of sandstones, it is unlikely that this weathering process would be effective for arid region carbonates. On the other hand, both Farrand's (1985) and my own observations have documented the production of coarse, clastic carbonate sediments in caves and rockshelters located the semi-arid and arid regions of the Middle East.

Chapter 5

Southern Alberta Rocky Mountains

INTRODUCTION

Two localities were examined in the southern Alberta Rocky Mountains (Figure 40); Racehorse Creek Rockshelter (near Crowsnest Pass) and January Cave (below Plateau Mountain in the Highwood Range). Racehorse Creek Rockshelter is formed in lower Cretaceous volcanic rock and yielded a Holocene record of human and animal occupation. January Cave is formed in lower Mississippian limestone and yielded a paleontological record extending back to approximately the mid-Wisconsinan. Both sites lie within the area of Wisconsinan Montane ice.

REGIONAL CLIMATE

Climatic data for the study area is presented in Table 11 below. Racehorse Creek Rockshelter lies within the subalpine portion and January Cave within the alpine portion of the environmental classification. The area in general is under the influence of Arctic (Polar Continental) air masses in winter and Mild Pacific air masses in the spring, summer and early Fall. This study area is on the eastern flanks of the Rocky Mountains which greatly affects the local weather patterns. In the later fall and winter, the southern Alberta foothills often experience relatively mild weather due to the blocking of Arctic air systems (Bryson and Hare (1972).

LATE QUATERNARY HISTORY AND PALEOCLIMATOLOGY

In the foothills area, Fulton et al. (1986) relate the Erratics Train Advance, Buffalo Lake Till, and Waterton II and III of Stalker and Harrison (1977), as well as the Cordilleran Ernst Till of Alley (1973) to the early Wisconsinan Glaciation. As Cordilleran ice is believed to have coalesced with Laurentide ice during the early Wisconsinan interval, the sites to be discussed below must have been buried beneath ice and received only glacial sediment during the early Wisconsinan. Fulton et al. (1984) date this interval, largely by reference to marine oxygen isotope stages, to between 75,000 and 64,000 yr BP.

Recently discovered evidence suggests that much of southwestern Alberta was free of ice during the mid-Wisconsinan (Jackson 1979, 1980b, Mott and Jackson 1982, McDonald 1982), a period that has been named the Watino Nonglacial Interval on the prairies of western Canada, and dated from before 52,000 to perhaps 23,500 B.P (Fenton 1984). Fossil evidence from a number of prairie sites indicates that conditions during this interval roughly resembled the modern day climate of the prairies or were somewhat cooler (Stalker 1977, Delorme, in Fenton 1984). No paleoclimatological evidence is forthcoming directly from the study area.

The late Wisconsinan Laurentide glacial interval, named the Lostwood Glaciation on the western Prairies, extended through south-central Alberta, leaving an ice-free wedge in southwestern Alberta sometime after 20,000 yr BP (Rutter 1984). Retreat of Laurentide ice is believed to have begun by at least 14,000 yr BP (Fenton 1984). The Cordilleran equivalent of the Lostwood Glaciation is the Fraser Glaciation of British Columbia (Armstrong et al. 1965, Fulton 1984, Fulton et al. 1986).

Late Wisconsinan advance of Cordilleran ice is believed to have ensued around 25,000 yr BP (Fulton 1984, Fulton et al. 1986) on the basis of correlation with dated materials in central and western British Columbia. The retreat of ice from the mountains of southwestern Alberta is believed to have begun around 13,000 yr BP and been complete by ca. 10,000 yr BP (Fulton 1984, Jackson et al. 1982). Levson and Rutter (1989) indicate

that the Jasper townsite, to the north of the study area, was free of ice by ca. 12,000 yr BP. In the area of Banff, well-dated lacustrine sediments led Reasoner et al. (1989) to suggest that montane ice had retreated up the Bow valley into cirques by 10,100. Dates from the lower Kananaskis Valley and Crowsnest Pass indicate these areas were free of ice by at least 10,400 and 14,470 yr BP respectively (Jackson and Pawson 1984).

Rutter (1980, 1984) has summarized the evidence for ice-free conditions in the foothills and southwestern prairies of Alberta during the late Wisconsinan. Fullerton and Colton (1986) dispute this contention and suggest that ice extended from southern Alberta down into Montana.

Holocene Paleoclimate

Luckman and Osborne (1979), and Osborne (1982, 1985) provide evidence for two Holocene glacial advances in the Rocky Mountains of southern Alberta which they name the Crowfoot advance and the Cavell advance. The Crowfoot advance is believed to have been an early Holocene glacial advance (pre-Mazama ash and probably post-Glacier Peak ash according to the authors). The Cavell advance is believed to be late Holocene (Neoglacial) in age (1000-800 yr BP to early 18th and mid- 19th Century). Gardner and Jones (1985) on the basis of dated overridden organic matter, postulate a further advance of the Boundary Glacier between ca. 4200-3800 BP.

Leonard (1986) examined lake sediments in Banff National Park for evidence of up-valley ice margin fluctuations. There is evidence for an increased ice extent shortly before 7500-7000 yr BP (possibly correlative with Crowfoot advance) and the time between 4000 and 3000 yr BP was one of reduced ice extent, with possibly a small readvance at ca. 5000 yr BP.

Osborne (1982), using evidence from Holocene advances of glacial termini discusses a period of of warmer, drier conditions lasting about 1000 to 2500 years before 6000 yr BP. Subsequent conditions were cooler and wetter after 6000 to 3000 yr BP. Following approximately 3000 yr BP, conditions were relatively cool and wet, leading to glacial margin fluctuations.

Luckman and Kearney (1986) using $\delta^{18}\text{O}$ ratios, pollen and macrofossils in alpine bog sites in the Maligne Range, estimate periods of higher than present temperatures and treeline ca. 8800-7500 yr BP and 7200-5200 yr BP. The period between about 7400 and 7300 yr BP is believed to represent a time of near modern timberline.

Beaudoin (1986) used *Picea/Pinus* ratios from a pollen core in Jasper National Park to infer Holocene vertical migration of the timberline. Her results suggest a period of higher than present timber line between 6540 and 1480 yr BP, with a minimal elevation occurring ca. 4210 yr BP. Between 1480 and 540 yr BP, timberline was lower than present but rose again after 540 yr BP. Beaudoin (1986) relates timberline fluctuations to temperature and believes that overall a period of mid-Holocene warming with a period of mid-late Holocene cooling corresponded to minimum values around 4210 yr BP, a fact consistent with evidence of late Holocene glacial advances from the Boundary Glacier (ca. 4000 yr BP; Gardner and Jones 1985) and other southern Albertan glaciers (Osborne 1982).

Driver (1978) has analyzed a pollen core from Crowsnest Lake, approximately 20 km from Racehorse Creek and 70 km from Plateau Mountain and January Cave. His outline spans only the Holocene and is reproduced below:

- Zone 1 - 9000 to 7000 yr BP slightly warmer and drier than present;
- Zone 2 - 7000 to 6000 yr BP still warmer and drier;
- Zone 3 - 6000 to 3000 yr BP cooler and wetter (but somewhat warmer and drier than today);
- Zone 4 - 3000 to present colder and wetter (modern conditions).

This sequence is in general agreement with pollen evidence from interior British Columbia where Alley (1976) indicates a warmer drier climate (than today) between approximately 8400 and 6600 yr BP. Fulton (1984) reports evidence for warmer conditions until 5200 yr BP on the basis of wood fragments beneath modern snow and ice fields in interior British Columbia. Cooler conditions for the late Holocene (3000 to present) are also suggested by alpine glacial advances following 3000 yr BP (Fulton 1971, 1984) and widespread advances following approximately 200-300 yr BP (Clague 1981).

Although much remains unclear concerning the late Quaternary history of the study region, the evidence is relatively clear for several distinctly different climatic episodes of greater or lesser severity. It would be reasonable to expect to detect Holocene climatic variation at Racehorse Creek Rockshelter and perhaps the entire span from Mid-Wisconsinan through late Holocene at January Cave.

RACEHORSE CREEK ROCKSHELTER (DkPp 11)

Location and Description

Racehorse Creek Rockshelter is located approximately 20 km north of Crowsnest Pass, approximately 50 m north of Racehorse Creek at 49° 46' N, 114° 27' W, at an elevation of approximately 1695 m. The shelter is formed in a near vertical cliff of porphyritic analcite phonolite, bearing phenocrysts of sanidine, garnet, and pyroxene of the lower Cretaceous Crowsnest Formation (Pearce 1970). The shelter is situated at the top of a colluvial apron consisting of large angular blocks of the local volcanic rock bordering the cliff-face.

The site was tested by Russell Brulotte, University of Alberta, as part of an archaeological testing program in the Racehorse Creek Drainage (Brulotte 1983). Prior to excavation this very small shelter stood approximately 2.5 m high, and was 3 m wide and 2 m deep (Figure 41). Brulotte excavated one 1 x 2 m test pit in the shelter and recovered a small amount of archaeological material (primarily stone artifacts) and abundant micropaleontological record. I visited the site briefly during Brulotte's excavations in 1982 and again in 1983.

The local porphyritic phonolite forming the walls and ceilings is extensively and finely jointed in the vicinity of the shelter, while areas of the cliff above the shelter possess a more coarse-grained joint system. It seems clear that the fineness of the joint system resulted in more rapid weathering in this area producing the small reentrant that constitutes the shelter.

Prior to excavation, the floor of the shelter was occupied by one or more rodent species for nesting as the surface was littered with grasses, leaves, and branches of the local poplar tree.

The primary responsibility for lithostratigraphic subdivision at Racehorse Creek Rockshelter lay with Brulotte. Therefore, the discussion to follow will deal only briefly with this aspect of the site.

Sample Collection

Samples used in the present analysis were collected by Brulotte during excavation of the shelter in 1982. Samples were collected from 50 x 50 cm squares corresponding to the 10 cm thick arbitrary excavation levels. The sample column was placed at the northwest corner of the juncture between two 1 x 1 m excavation units. Sample bags were labelled and sent to the Geoarchaeology Laboratory of the University of Alberta, for processing.

Stratigraphy

Because I was not present throughout the excavations of Racehorse Creek Rockshelter, Brulotte outlined the lithostratigraphy of the site. I visited the site again after the excavation

and revised Brulotte's original lithostratigraphic assessment. A slightly revised revision of Brulotte's (1983) profile is reproduced in Figure 42.

Brulotte (1983) divided the shelter fill into three lithostratigraphic units on the basis of coarse clast content, organic matter content, and bedding. In broad outline, my lithostratigraphic determinations parallel those of Brulotte (1983). Three fairly distinct lithostratigraphic units exist, defined largely on variation in coarse and fine fractions and, to a lesser extent, on the percentage of organic matter present in units.

Unit I: Surface to about 40 cm, organic rich (31.3-13.04%), very dark brown (10YR2/2), matrix supported gravel (clast >1 cm constitute between 54.7-31.7% of organic-free sample). In the upper parts of the unit undecomposed organic matter constituted an appreciable part of the sedimentary matrix.

Unit II: 30 cm thick unit consisting of very dark grayish brown (10YR3/2-2/2) to dark brown (10YR3/3) matrix supported gravel (clast >1 cm constitute between 22.2-37.3% of sample). Within this unit occurs a 5 cm thick lense of charcoal.

Unit III: Approximately 1 m thick, matrix to clast supported gravel (32.0%-59.6%), within matrix of (dark grayish brown to olive 5Y 4/3) sandy-silty-clay resting on sloping bedrock floor.

Characteristics of the Sediment

Sedimentological data for Racehorse Creek Rockshelter is presented in Figure 43 and the discussion to follow is keyed to that diagram. A large quantity of the data relating to the fine fraction was lost. As these data are incomplete, they will be presented only in verbal form.

Coarse Fraction

The percentage of the sample (organic free) consisting of coarse fraction fragments ranged between 11.1% and a high of 59.6% by weight. The mean size of clasts was relatively small, averaging 3.22 cm, in general paralleling the spacing between joints in the wall and ceiling rock. The joints varied between approximately 4.8 cm to 1.1 cm in maximum dimension with a mean of 3.54 cm.

There is an overall slight tendency for the mean size of clasts to decrease down the section. This tendency is matched by an apparent down-section increase in the contribution of the medium fraction (Figure 44). The easiest explanation for this relationship lies in the ongoing mechanical weathering of clasts buried beneath overlying sediments, reducing the size of clasts in the coarse fraction, though perhaps not reducing significantly the overall weight percent. Alternatively, these data may suggest that a greater proportion of clasts between 1 cm and 2 mm were produced during earlier phases of the shelter's history.

Irrespective of depth, coarse and medium fraction clasts were uniformly angular to rarely subangular. Due to the almost complete angularity of specimens, these data are not presented in a figure form. This great angularity of clasts is of course not unexpected given the regional climate of Racehorse Creek Rockshelter and the volcanic rock in which it formed.

Fine Fraction

The organic matter content of the section reaches very high levels at the surface and declines rapidly below Unit I to average between 3 and 7% by weight. This decline seems to imply a time-dependent decay of organic matter within units as they are successively buried and no longer receive additional organic matter. Another possibility, outlined in the final section is that its morphology changed through time; the shelter received greater quantities of organic matter from biological agencies during later periods of its history.

The sand/silt/clay ratios remain fairly constant throughout the profile, except for the upper three samples which exhibit much higher clay fraction percentages than lower

samples. The mean size of the fine fraction is fairly constant, varying between 5.55 ϕ and 6.22 ϕ (medium silt) in the lower samples and 8.91 ϕ (clay) in sample 2B. All samples are very poorly sorted ($\sigma_1 > 2\phi$), and the majority, particularly in the lower samples are extremely poorly sorted ($\sigma_1 > 4\phi$).

These data for the fine fraction indicate that this shelter has received a fairly constant, poorly sorted suite of sand, silt, and clay throughout its history. In the upper 30 cm or so, the fine fraction came to be dominated by a strong increase in the clay fraction. The correlation between organic matter and increased fine fraction suggests that these two variables are related in some fashion.

Age of the Deposit

One radiocarbon date of 3050 ± 130 yr BP (BETA?: no citation given in report) was determined on charcoal collected from Level 5 (Brulotte 1983: 62). Level 5 occurs near the base of Unit 1 as defined in this study, at a depth of approximately 50 cm below the surface. Extrapolation of this single date to the surface yields an average sedimentation rate for the last 3000 years of approximately 16.3 cm 1000⁻¹ years. This value is similar to, though slightly higher than, most rates reported from the Pryor Mountain study sites.

Sedimentary processes

It was noted above that the organic matter content decreases progressively down the exposed section. This distribution may reflect progressive decay, but I believe the upward increase in organic matter is more a function of the progressive change in shelter morphology, and its increased suitability as a nesting site for various mammals. Below I have diagrammed (Figure 45) a proposed scheme for the evolution of the shelter as a function of cliff retreat and elevation of the talus apron at the base of the cliff. Not until the talus slope intersected the base of the ledge of the shelter would sediment accumulate to any substantial degree within the shelter. At this point the shelter became suitable for use as a nesting site with abundant escape routes through the coarse talus adjacent to the site.

The contribution of the coarser clasts (> 1 cm) to the sediment samples varies throughout the section with several distinct peaks and valleys. The overall abundance of gravel-sized clasts must reflect their frequency of production and accumulation within the shelter. Therefore, lacking any lithological explanation for increased production of clasts in certain levels, changes in the conditions promoting removal of clasts from the walls and ceilings must have fluctuated in a similar fashion. Given the regional climate and local microenvironment, changes in the frequency and depth of freezing and thawing events, combined with variation in moisture levels on the ceiling and wallrock at particular periods, must have produced the observed variation in frequency of the coarse, angular clasts. Two peaks in coarse clast frequency are noted at levels 14-13H and 9-8B. In addition, a final peak occurs in the surface sediment unit.

The lack of dating precision makes it impossible to relate specific peaks and valleys to externally defined episodes of changed climate. However, from the evidence presented at the beginning of this section, it is clear that the region underwent several periods of climatic oscillation during the Holocene. The bulk of evidence, primarily from glaciological and palynological studies, suggests that following a late Pleistocene period of extreme cold, the mid-Holocene experienced higher than present temperatures. The late Holocene has been progressively cooler, and/or more moist than other portions of the Holocene.

It is possible, therefore, that the lower portions of Racehorse Creek Rockshelter represent sediment which accumulated during the late Pleistocene/early Holocene when montane glaciers were receding in all the major valleys of the Rocky Mountains. Levels 7B-5B may represent the mid-Holocene period of either increased temperatures or decreased moisture levels, both of which would have slowed the rate of production of

coarse clastic debris from the ceiling and walls of the shelter. Finally, the upper samples may represent filling of the shelter during the late Holocene Neoglacial, when temperatures were presumably lower and/or precipitation levels higher.

It was also noted that the coarse clasts decrease in mean diameter down the section, even where overall abundance of gravel-sized clasts is great. I believe this pattern reflects the ongoing comminution of clasts as they lie buried beneath overlying sediments. It was unfortunate that this hypothesis could not be independently tested during removal of the sediments by identifying in-situ fractured clasts within the lower depositional units.

The contribution of clay-sized particles increases dramatically in the upper depositional units. This pattern is linked to a simultaneous increase in organic matter in the upper units. As discussed earlier, the organic matter and clay may reflect tracking in by various small mammals. In addition, the presence of nesting materials would have acted to retain finer-grained materials that might have been washed out in lower, coarser units.

Discussion

Racehorse Creek Rockshelter is a small reentrant, formed as a result of higher rates of physical weathering around a localized zone of heavily jointed volcanic rock. The morphology of the cavern resembles that of a half-circle on the vertical cliff face. The orientation of the floor of the cavern is a result of weathering of both the surrounding cliff and the shelter itself. The shelter would not have begun to accumulate sediment until accumulation of the talus apron at the base of the cliff built up to the height of the shelter. From that point onward, sediments produced from the walls and ceiling of the shelter would have remained largely within the shelter.

Once sediment began to accumulate within the shelter, the texture of the sediments depended upon the rate of physical weathering within the shelter. Periods of low frequency of physical weathering produced finer-grained sedimentary units. In addition the changing morphology of the shelter acted to accumulate both organic matter and very fine-grained sediment in the upper unit of the shelter. The variations in coarse clastic content in this shelter are very tentatively correlated to periods of climatic change inferred from other data.

JANUARY CAVE (EbPp-63)

Location and Description

January cave (50°11'N, 114°31'W) is located in the Kananaskis Park, directly below Plateau Mt. at an elevation of 2040 m in the Livingstone Range of the Canadian Rocky Mountains. The cave lies in a forested, limestone cliff, within the Subalpine region (Land Region 6, AENR Report no. 94, 1979). The cave formed in lower Mississippian Limestone (Livingston Formation), overlain by Pennsylvanian quartzite, sandstone, arenaceous dolomite, and sandstone (Figure 46). The local climate of this region is cold and wet in winter, and cool and moist in the summer months. Maximum precipitation occurs during June (total precipitation, ± 600 mm), while approximately 60% of the total precipitation falls as snow in winter. Alpine tundra ranges from 2440 m to 2590 m on the upper portions of Plateau Mountain. Locally the talus and colluvial slopes are vegetated primarily by Engelmann spruce (*Picea engelmannii*).

January Cave is composed of two portions, an exterior rockshelter some 19 m long and from 2.5 to 6 m wide, extending back from the dripline (Figure 47: From Burns 1984). Opening onto the rockshelter is a low-ceilinged cave (ca. 1 m high) of approximately 12 m x 8 m, with several small, tubular corridors leading off from it. Prior to excavation, the surface of the rockshelter was covered with 10 to 15 cm of organic matter, primarily in the

form of wood rat (*Neotoma cinerea*) and Bighorn sheep (*Ovis canadensis*) dung (Burns 1984).

The rockshelter was initially excavated in 1969 by T. Habgood and M. McEachern, University of Alberta, and reexcavated in 1973 by J. Brink, Archaeological Survey of Alberta. Both projects were primarily in search of archaeological evidence. Excavations by J. Burns, Provincial Museum of Alberta, in 1974 were part of a micropaleontological research project.

PHYSICAL STRATIGRAPHY

The lithostratigraphic section exposed in January Cave is visually homogeneous. This impression is also born out by granulometric and morphological analyses to be presented later. Due to sediment homogeneity, and the inability to subdivide the section into distinct lithostratigraphic units, samples were collected in arbitrary 5 to 10 cm collection levels.

The depth of the sediment accumulation in this part of the shelter varies from 1.00 to 1.95 m from the surface to the underlying bedrock. The section I examined extended approximately 1.15 m below the datum set by Burns (1984). Since there is by definition only a single lithostratigraphic unit, the discussion to follow will focus on variations within the entire section in the various sedimentary parameters examined.

Characteristics of the Sediment

There is a gradual decrease in the gravel fraction of the sample with a small peak at approximately 75 cm of 23% (Figure 48). From a maximum value of 29.7% for the surface sediment, to 4.2% at the base of the section, there is a difference of 25.5% in the contribution of the coarse fraction. Although this spread is relatively large, the change between adjacent levels is nowhere more than 11.4%. Along with a down-section decrease in the coarse fraction, the M_{dmm}/M_{zmm} of gravel-sized clasts also decreases gradually down section except for, again, an increase between 65 and 75 cm. Distribution of clast sizes within the coarse fraction fluctuates widely down the section. The greatest contribution of the B-fraction also occurs in the uppermost sample collection level and then remains fairly constant down to the lowermost collection level. This downward decrease in clast size is also reflected in sand-silt-clay values, where the percentage contribution of sand-sized clasts decreases down section. Silt-sized clasts increase gradually down-section to maximum values in the lower parts of the section.

The observed down-section decrease in coarseness of the clasts either indicates that the severity of mechanical weathering processes was most intense in recent times, or that time dependent weathering of clasts in situ (either mechanical or chemical) took place, reducing the coarseness of clasts in relation to their time residing in the deposit.

Organic matter content is very high in the uppermost sample and decreases sharply at 35-45 cm, where it remains fairly constant until reaching a minimum level in the lowermost sample. At this site it is likely that the downward decrease in organic matter reflects time-dependent decay within the section.

PALEOENVIRONMENTAL STUDIES

Palynological and paleontological studies were carried out for and by Burns (1984) on January Cave, and these studies have a bearing on the present study. His studies revealed a very homogeneous fauna associated with a pollen spectra indicating a treeless terrain.

Palynological investigations were conducted by Dr. J.H. McAndrews, Dept. Botany, Royal Ontario Museum, on palynological samples taken from the south face of Unit SE every 10 cm from 30-140 cm and at 180 cm below the datum used by Burns (Burns 1984:49). In addition, McAndrews sampled the modern pollen rain, but it is unclear exactly where traps were located within the shelter.

Modern pollen rain was dominated by arboreal species, particularly *Pinus*, *Juniperus* and *Picea*, with non-arboreals including Gramineae, Liguliflorae and Cyperaceae being only sparsely represented in percentage counts (Burns 1984:50a).

Analyses of the cave sediments on the other hand, indicated an extreme paucity of arboreal pollen, which nowhere contributed more than 7% of the total in any one sample, in which case it is either *Pinus* spp. or *Picea* spp.. Dominants in the cave sediment samples were Caryophyllaceae such as *Claytonia*, and Tubuliflorae. Minor constituents were *Phlox* and *Polemonium*. As noted by Burns (1984) the dominant species are all primarily entomophilous varieties. Anemophilous varieties include rare grasses (Gramineae) and sedges (Cyperaceae). In addition, a high percentage of grains were unidentifiable due to extreme corrosion.

Burns (1984) interprets the pollen assemblage throughout the section to indicate an essentially treeless, alpine tundra. In particular, as arboreal species fail to make a significant appearance throughout the section, Burns (1984) suggests that the early Holocene rise in arboreal species, noted in other local palynological studies, indicates that deposition in the shelter essentially ceased following late Wisconsinan times.

DISCUSSION

Burn's (1984) use of the pollen spectra to argue for alpine tundra conditions in the vicinity of the cave, and particularly to argue against presence of trees in the area throughout the deposition of the cave sediment, is questionable. The use of pollen derived from cave sediments is fraught with difficulties that make a simple environmental reconstruction difficult. Low's (1984) study of pollen entrapment in caves and rockshelters in the Pryor Mountains suggests that entomophilous pollen will tend to be overrepresented in relation to anemophilous pollen in the cave earth, even if not necessarily in traps designed to collect wind transported pollen. As Burns (1984) was comparing pollen spectra from sediments within a wind-sheltered section of the shelter to modern pollen rain of anemophilous species, it is hardly surprising that very different pollen assemblages were obtained. Instead of recording changed environmental conditions, it may be more likely that the differences in pollen spectra are due to sampling of pollen introduced by two very different vectors (Low 1984). Although this evidence does not affect the interpretation of alpine tundra conditions based on the fossil mammal assemblage it does question the supporting evidence for these conditions.

CHRONOLOGY OF THE DEPOSITS

One date of $23,100 \pm 860$ BP (GaK-5438) was obtained from combined microfauna bone from the base of Burns' levels 13-16, with an average depth of between 120 and 160 cm (Burns 1980). Two additional dates of $31,900 \pm 1400$ (levels 14-16; QL-1738) and $33,500 \pm 1100$ yr BP (level 7; QL-1737) were obtained from the collagen of mixed species (Burns 1991). Burns (1984, 1991) thought that the shelter deposits spanned only the late Wisconsinan, lacking sediments produced throughout the Holocene. The primary evidence for this suggestion was the lack of a major representation of arboreal species in the pollen assemblage obtained from the cave sediments. Additionally, Burns (1991) notes the lack of volcanic ash in the deposits. As discussed above, this negative evidence is probably not applicable as the lack of arboreal species can be explained more simply by the operation of very different vectors of pollen introduction to the cave. The lack of volcanic ash can be explained by the protected position of the shelter. It is therefore possible that Holocene sediments are in fact represented in the upper portions of the profile.

Using the date of 23,000 yr BP and a depth of 150 cm, an average sedimentation rate for this cave of approximately $6.5 \text{ cm } 1000^{-1}$ years is obtained. This rate of sedimentation is the lowest of any of the sites discussed thus far. If the shelter sediments only span the period between 33,500 and 23,100 BP, as suggested by Burns (1991), then the sedimentation rate is certainly less than $1 \text{ cm } 1000^{-1}$. Acceptance of Burns chronological

placement of the shelter sediments implies that erosion has approximately equaled the rate of sedimentation over the Holocene.

DISCUSSION OF SOUTHERN ALBERTA SITES

January Cave presents an example of a limestone rockshelter formed under fairly rigorous conditions of long, cold winters and short, warm summers, with a record apparently extending from the late Wisconsinan to the present. The research reviewed in the beginning of this chapter indicates that much evidence of significant Pleistocene and Holocene climatic variation exists. This climatic variation is, however, not reflected in the sediments, providing of course that the Holocene record is in fact represented. If the Holocene is not represented, an equally difficult interpretive problem exists in explaining the lack of sedimentation under what would appear to be ideal conditions for clastic sediment production.

In the absence of significant variation in the sediments, and with significant proxy evidence of climatic change, the explanation for the sediment homogeneity must lie in the intrinsic characteristics of the host rock. The lack of significant jointing focuses physical weathering processes inside the rock body instead of in fissures. The low gravel-sized clast values must indicate that weathering corresponds to microgelivation, or the granular disintegration of a rock body, instead of the production of gravel sized clasts. Alternatively, post-depositional clast reduction may well have occurred, though there exists no positive evidence for this process, other than a reduction in the percentage of coarse clasts with depth.

Racehorse Creek Rockshelter presents a sedimentary record extending perhaps back into the latest Pleistocene. The mean size of coarse fraction clasts at this site remains fairly constant through time, apparently the result of joint spacing in the volcanic rock comprising the shelter. However, fluctuations in the percentage contribution of the coarse fraction may relate to climate changes across the late Pleistocene/Holocene boundary and throughout the Holocene.

Comparison diagrams for mean size of clasts and percentage of the coarse fraction are presented in Figure 49. The values for mean size at January Cave overlap considerably with those at Racehorse Creek Rockshelter, though the January Cave clasts may have originally been larger, and suffered post-depositional size reduction through time, as discussed earlier. The majority of all sediment samples from January Cave contain fewer coarse fraction clasts than those from Racehorse Creek Rockshelter.

Comparison of scatterplots and correlation coefficients for the mean size versus coarse fraction percentage are presented in Figure 50. These plots indicate that there exists a relatively high correlation for these two variables for sediments at January Cave, while sediments at Racehorse Creek Rockshelter exhibit little correlation.

I suggest that the lack of correlation between mean size and coarse fraction percentage at Racehorse Creek Rockshelter has to do with the pre-shaping of clasts by joints. Thus, regardless of the rate of coarse clast production, their size would be largely independent of the mechanical weathering process at work. I attribute the strong positive correlation at January Cave, on the other hand, to progressive, post-depositional clast size reduction.

Sedimentation rates at the two sites differ dramatically, at least over the periods of time for which this value was calculated. January Cave has evidently experienced a very slow rate of deposition over the late Pleistocene and Holocene. Racehorse Creek Rockshelter experienced rates in line with those discussed earlier from the Pryor Mountain sites, though significantly lower than published sedimentation rates from the late Pleistocene of southern France.

Chapter 6

Northern Yukon Sites

INTRODUCTION

Three excavated sites were examined along the upper-middle course of the Bluefish River, northern Yukon Territory, approximately 54 km southwest from Old Crow village, at 67° 9' N, 141° 45' W, at an elevation of approximately 600 m (Figure 51). The sites lie at the extreme western end of a long, carbonate ridge (Cambrian through Silurian) about 250 m above the Bluefish River. They are located within approximately 100 m or less of one another, and are erosional reentrants into Upper Cambrian through Silurian age limestones (Norris 1963).

As in the previous three sites studied, the primary goal of the present study was not to present a detailed microstratigraphic study of the sediments, as this work was the responsibility of others. For this reason, the detailed lithostratigraphy is left for later publications. The present study will concern itself primarily with the gross sedimentary products accumulated in these three caves over the latest Quaternary.

QUATERNARY PALEOENVIRONMENTS AND CLIMATE

The mid-Wisconsinan, Boutellier Interval (intervals of the late Pleistocene used in this study follow the proposals of Hopkins 1982) of eastern Beringia, is believed to have been a period of relatively warm, dry climate (Schweger 1982, Hopkins 1982). Although the picture is far from complete, evidence from several sites in the Yukon indicate retreat of Cordilleran and Laurentide (Hughes et al. 1981) ice during the mid Wisconsinan.

The late Wisconsinan full glacial (ca. 25,000-11,000 years ago) apparently witnessed maximum advance of Laurentide ice in the Yukon Territory (Hughes et al. 1981, Prest 1984). This period of time, referred to as the Duvanny Yar Interval in Beringia, is reconstructed by Hopkins et al. (1982), and Ritchie (1984), to have been treeless, herb tundra, consisting predominantly of herbaceous arctic-alpine taxa yielding relatively low pollen influx values to bog and lake sites. Abundant exposed braidplains, and drainage of several large impounded lakes, combined with the lack of vegetation, favored extensive aeolian transport and deposition in the study area. Ritchie (1984) reconstructs the late Wisconsinan climate by reference to areas with analogous vegetation on northern Banks Island and Victoria Island for the full glacial, and southern Banks Island for the late glacial. For full glacial conditions this would imply a mean annual temperature of around -12 to -15° C. Climatic modeling for the period 18,000 yr BP for Beringia as a whole suggests colder, drier winters and a later spring thaw compared to modern values (Gal-Chen 1982).

The period of time ca. 14,000-9000 yr BP was apparently one of rapidly shifting vegetation and, presumably climatic patterns throughout eastern Beringia (Hopkins 1982). Pollen (Ritchie 1984, Schweger 1982) and macrofossil (Delorme et al. 1977, Nelson and Carter 1987) records from this region record the time-transgressive (from south to north) movement of taxa to beyond their modern range. It is believed that these changes reflect a change from a herb to a birch-shrub tundra in northern Beringia, which are recognized as the "Birch Zone" in palynological diagrams on the basis of appearance and increased influx of *Betula*. To the south of the study area forests including *Pinus* and *Picea* apparently prevailed.

These paleoclimatic proxy data are thought to signal an abrupt change in climate, indicated time-transgressively due to the nature of plant and insect dispersal and migration (Hopkins 1982, Schweger 1982, Ritchie 1984). The climate of the span of time represented by sediments attributed to the Birch Zone is believed to have been more mesic,

with warmer and drier summers, and possibly increased precipitation during winter. Plant and insect macrofossils from the Ikpikpuk River (Nelson and Carter 1987) on the Arctic Slope of Alaska (to the northwest of the study area) and freshwater ostracods (Delorme et al. 1977) from sections along the Peele River to the southeast, indicate increased summer warming during the late Pleistocene to early Holocene. Range extensions of various taxa (e.g. *Populus balsamifera*) in dated pollen cores (Cwynar 1982) are also believed to reflect this changing climate. Ritchie (1984) suggests that the change in climate during the early Holocene occurred ca. 11,000 yr BP in the northwestern Yukon.

The mid to late Holocene (7,000 to present) is represented by an abrupt increase in alder (*Alnus*) percentages and influx, followed by more stable values to the present throughout the study area (Ritchie 1984). This paleoecological change presumably reflects climatic conditions similar to those at present, with lowering of summer insolation values following their maximum during the early Holocene.

MODERN ENVIRONMENT AND CLIMATE

A detailed description of the modern climate in the vicinity of these caves is hampered by the lack of weather stations in the immediate area. The nearest are the stations at Aklavik, Fort MacPherson, Dawson, and Shingle Point, all some distance from the study area (Ritchie 1984). The Bluefish Caves lie within the Continental Subarctic zone. Mean monthly temperatures for May to August in the northern Yukon range from 6.7° C to 12.7° C. Mean July averages measured at Old Crow Station are 13.8° C (Environment Canada 1981). Mean annual temperature in Old Crow is reported as -14° C by Lauriol et al. (1988), who also give a value for precipitation of 215 mm yr⁻¹ for Old Crow. Mean January temperatures are approximately -15° C (Bryson and Hare 1972). The mean annual fall of daily air temperature to 0° C occurs around the first of October and the mean annual rise above 0° C occurs around 15 May (Bryson and Hare 1972). The annual frost-free period ranges from 50-90 days in the Northern Yukon with approximately 40 days in the study area. Snow depth varies from 1-2 m during the winter months. Spring arrives in the period April to June with rapid warming and melting of snow.

DESCRIPTION OF THE CAVES AND MODERN DEPOSITIONAL PROCESSES

All three caves are very small reentrants (approximately 3 x 4 m) into a limestone bluff at the end of a long ridge overlooking the Bluefish River. The ceilings and walls of all three caves are coated with greater or lesser deposits of secondary carbonate precipitates and moss. The presence of this precipitate, several millimeters thick, argues that production of mechanically weathered debris from the ceiling and walls of the caves has been extremely slow in the recent past, allowing time for the extensive buildup of this secondary precipitate. Further evidence for a relatively slow rate of production of mechanically weathered clasts will be presented later. There is a lack of any appreciable build-up of limestone clasts within the caves proper.

Dominant processes responsible for the accumulation of sediments in these caves stem from three primary sources: aeolian deposition of fine-grained sediments; production of mechanically disaggregated debris from the cliff face above and to the sides of the shelters; and accumulation of organic matter from the vegetative cover and animal activity. Post-depositional processes include downslope movement of the fine-grained stratigraphically lower sediments and vertical movements and mixing of sediments, primarily within the caves themselves due to frozen ground phenomena.

Surficial sediments were examined in a number of other small caves, rockshelters and simple overhangs in the general vicinity of the Bluefish Caves. These sediments were characterized in all cases by the presence of a thick humus build-up, with abundant coarse limestone clasts. In general, these shelters were extremely small, with a ceiling not more

than 0.5 to 1 m in maximum height. Thus sunlight would reasonably be expected to extend to a fair distance within these sites.

Another cave was examined in the vicinity of the Fishing Branch River. This cave was remarkable in that the floor was covered to a depth of at least 5 cm by dried dung, probably porcupine. From the exploratory trench sunk into the cave it appears the cave has acted as a catchment for animal dung for some time. This cave was also notable for the evidence of mechanically disaggregated, coarse clast production, indicated by the abundant, angular spalls littering the cave floor. The walls and ceiling of this cave were extensively jointed by two prominent joint sets at approximately 45°. No permafrost was present at this site either.

STRATIGRAPHY

At all three of the Bluefish Caves, the lithostratigraphic section can be roughly divided into three major stratigraphic units. A lower stratum, the loess unit, overlay bedrock and consisted of silt to silty clay with rare gravel-sized clasts, averaging about 0 m to 30 cm in depth. A middle stratum, the loess/rubble unit, had a similar silt-rich fine fraction but a greater percentage of gravel-sized clasts averaging between 30 cm and 1 m in depth. An upper unit, consisting of a stoney moss humus also about 0.5 m to 1 m in depth, is known as the humus/rubble unit (this subdivision is less detailed than that presented by Cinq-Mars 1979 and follows more closely that of Ritchie 1984). The loess and loess/rubble units are believed to range from approximately 12,900 to 15,500 yr BP based on radiocarbon analyses of vertebrate fossils (Ritchie 1984). Vertebrate remains include horse, mammoth, dall sheep, caribou, bison, wapiti, muskox, and numerous small mammals.

SAMPLE COLLECTION

At all sites, samples were collected as part of the ongoing excavation. This required removing sediment from a 25 x 25 cm excavation unit 10 cm or more in thickness. Samples were then labelled, bagged, and carried away from the site to process. They were first laid out on clear plastic for 24 hours to dry and then weighed. The sample was then sifted thru two sieves to produce the coarse fraction (greater than 1 cm), B fraction (2 mm-1 cm), and the C fraction (less than 2 mm). After several 500 ml whirlpack bags were filled with fine fraction, the remainder was sifted to look for potential archaeological materials and then discarded.

CAVE I

Cave I, approximately 3 m wide x 4 m deep and 3.5 m high (ceiling at dripline) is a small reentrant with a northerly orientation (Figure 52). The cave floor is relatively flat, and slopes steeply off towards the north beyond the dripline, where the bedrock walls of the ridge form an amphitheatre-like enclosure.

The roof and wall rock of Cave I is finely jointed, and covered with an extensive buildup of secondary carbonates, such that jointing is obscured within the cave. A very sparse cover of lichens exists on the inner walls and the sediment surface is sparsely covered with moss, grasses and ferns.

Lithostratigraphy

The lithostratigraphic sequence is very complex. However, for purposes of this study it is useful to simply divide the sequence into an overlying humus/rubble unit, a mixed loess/rubble unit containing elements of both the over and underlying units, and a lower loess unit (Figure 53, Table 12). The actual complexity of lithostratigraphic units at Cave 1 relates to small solifluction lobes and occasional lenses of pure limestone gravel probably derived from the cliff face above the cave.

The humus/rubble stratum, is a clast-supported (58% gravel content >1 cm), organic rich (Om=18%), very poorly sorted, sandy, silty clay. This stratum thickens beyond the

neck near the cave entrance (approximately 1.5 m beyond the modern dripline), and the underlying strata become significantly thinner. It is quite likely that the neck at the cave entrance has aided in the preservation of underlying units within the cave proper, as outside the entrance considerable solifluction of the underlying strata has occurred. Toward the rear of the cave (approximately 2-3 m back from the dripline), the upper humus/rubble unit thins to only several centimeters thickness. Apparently, this indicates very slow rates of accumulation of mechanically disaggregated limestone clasts and organic matter, only a short distance within the cave.

Beneath the upper humus/rubble unit, in the mixed loess and rubble units and the lowermost loess unit, the coarse fraction clast content decreases somewhat but is always greater than 40% of the total sample. Similarly, organic matter content decreases dramatically in the lower stratigraphic units, never exceeding 8%. The lower units are generally finer-grained (less sand) and better sorted.

Samples were collected from near the rear of this small cave (sample numbers 19-1 thru 4 and 18-1 and 2) approximately 1.5 m inside the cave. Sample 18-1 comes from the uppermost humus/rubble unit. Samples 18-2 (much of the data concerning the coarse fraction is missing from this sample), 19-1 through 3 were taken from the mixed loess/rubble unit. The lowermost loess (in bedrock pockets) was not exposed at this point in the section.

Characteristics of the Sediment

Coarse Fraction

Texture, Morphology and Concretions

The coarse fraction (>2 mm) generally comprises a large percentage of the total sample (Figure 54); except for sample 19-2 from the loess/rubble unit, samples are all 50% or greater coarse clasts by weight. These include both the humus/rubble, and loess/rubble units. In particular, the humus/rubble sample contains 67% coarse clasts >1 cm. The median (Md_{mm}) and mean (Mz_{mm}) are always approximately 4.0 cm or greater for all samples. These data suggest that production of gravel-sized clasts, relative to the introduction of finer-grained sediment, has been relatively rapid, or that the subsequent size reduction of gravel-sized clasts has been relatively slow, throughout the history of the cave.

Figure 54 illustrates the variable importance of the thinly-bedded limestone (slabs) to the sediment column. The thinly-bedded bedrock stratum from which these clasts are derived is located on the southern arm of the cave. The fact that significant quantities of these clasts are present only in the uppermost strata may indicate that this bedrock unit was somehow not well exposed during earlier phases of the shelter's history. Alternatively, and in my opinion more likely, these thin, relatively fragile clasts suffered rapid, post-depositional breakup, reducing most of the original clasts to less platy, more stable forms.

Roundness values are somewhat variable for the Cave I samples. Angular to subangular clasts always constitute at least 50% and commonly 80% by weight of the sample. Subrounded to rounded clasts constitute an important part of the coarse fraction only in 1 sample. The upper humus/rubble sample is significantly more rounded than lower samples, where rounded clasts are non-existent. Maximum angularity occurs in samples 19-1 and 2 in the mid portions of the lower, loess/rubble unit. Secondary carbonate concretions were present in low quantities (<10%) in all but samples 19-1 and 2, and covered approximately 40% of the clasts in the uppermost sample, 19-3.

The fact that maximum roundness of clasts, including fully rounded specimens, occurs in only the uppermost sample, suggests to me that, as was seen previously in the Pryor Mountain study sites, increased organic matter content in the uppermost sediments has acted through time to place clasts in this portion of the profile in a wetter microenvironment. It is additionally quite possible, though untestable, that clasts in lower levels of the site were within the permanently frozen layer during the late Pleistocene. A third hypothesis to explain the lower degree of rounding in lower levels is that

sedimentation rates could well have been more rapid, with a greater influx of aeolian sediment. More rapid burial, with rapid movement of clasts away from the more moist, near surface environment (i.e. proximity to late-lying snow banks) may also have protected these clasts from more active chemical rounding.

Fine Fraction

The fine fraction of samples is uniformly enriched in organic matter with values ranging from <10% for the loess/rubble stratum to >20% by dry weight in the upper sample. Values decrease significantly from the upper humus/rubble unit into the loess/rubble unit. Given the rapid decrease in organic matter in the lower unit, I would argue that the decrease is not due simply to time-dependent decay but rather, indicates more rapid rates of organic matter buildup in the upper levels of the site.

Mean ($Mz\phi$) and median size ($Md\phi$) for C fraction sediments lie in the fine, to very fine silt range (6-8 ϕ) for all samples, typical values for loess sediment. There exists no significant difference in the mean size of fine fraction clasts in the upper humus/rubble stratum. The silt content of the loess/rubble samples is, however, significantly higher than upper samples, with a narrow range of between 71 and 73% of the fine fraction for loess/rubble samples, compared to 48% for the humus/rubble sample. All samples are poorly to very poorly sorted, though this is to be expected in a mixed aeolian, colluvial depositional environment. The loess/rubble samples exhibit consistently better sorting than the humus/rubble sample, and all fall within the range of sorting values reported for loess sediments elsewhere in the world (1.50-2.16). All samples are fine-skewed (.1 ϕ .3 ϕ), except sample 19-3 which is coarse-skewed. Loess samples are meso- to leptokurtic, indicating better sorting in the central portion of the distribution. The humus/rubble sample is platykurtic, suggesting poorer sorting in the central portion of the distribution.

The homogeneity of the fine fraction of the loess/rubble samples is striking, and suggests that deposition was fairly uniform throughout the history of the shelter represented by these sediments. Further, these data argue against redeposition of the fine fraction and suggest that these sediments have suffered little mixing throughout their history. Poorer sorting, and a lower silt content for the humus/rubble sample suggests that during this portion of the shelter's history, aeolian processes ceased to dominate the origin of the fine fraction.

Diagenetic and post-depositional Processes

The most significant post-depositional process operating at this as well as at other caves, was the vertical and horizontal movement of sediment, either as flowing lobes of saturated, silt-rich sediment, or loess-originating frost hummocks. The latter process served to mix portions of the upper loess unit with the overlying organic rich sediment, adding organic matter. The former process does not appear to have led to significant mixing of sediment but resulted in a great deal of lateral sediment movement.

Paleoenvironmental Evidence

Palynological samples were taken by Cwynar and Ritchie (Cwynar in Cinq-Mars 1979; Ritchie et al. 1982) from an approximately 150 cm section at Cave I. The lower portion of the pollen diagram (ending at approximately 125 cm) is placed within a herb tundra zone. These samples apparently came from the lower loess units at the Cave.

Zone II is marked by a percentage increase in *Betula* at approximately 125-46 cm below the surface. This zone presumably lies within the loess rubble and up into the humus rubble units. On the basis of comparison with other pollen records in the region, the beginnings of the *Betula* rise should indicate an age of around 13,000 yr BP. As indicated earlier, the *Betula* rise is believed to result from increased summer temperatures, the temperature rise probably predating the rise in *Betula* pollen percentages.

The uppermost Zone III is marked by a decrease in the percentage of *Betula* pollen and an increase in *Alnus*. This zone falls completely within the humus rubble units and by comparison with other dated sections in the region may date from around >8000 years ago.

Age of the Sediment Accumulation and Sedimentation Rates at Cave I

Cinq-Mars (1979) reports one radiocarbon date from the Cave I sediments. A ^{14}C date of $12,900 \pm 100$ yr BP (GSC-2881), determined on a sample *Equus* sp. femur collected from the lowermost levels in Cave I (loess unit). As discussed by Cinq-Mars (1979) this date is in general agreement with the palynological and paleontological remains, suggesting a late Pleistocene age of ca. 13,000 yr BP for the initiation of aeolian sedimentation at this site.

Using a date of ca. 13,000 years ago for initiation of sedimentation, and an average depth of sediment of approximately 130 cm, an average rate of sedimentation for this site of 10 cm 1000^{-1} years can be calculated. There is considerable evidence to suggest that this sedimentation rate varied significantly throughout the history of the deposit.

The evidence for aeolian deposition in the loess and loess/rubble units suggests that sedimentation rates for this unit may have been significantly more rapid than for overlying organic rich, rubble strata. However, without further dates it is impossible to say how much sedimentation rates may have varied through the history of Cave I.

CAVE II

Cave II is a small (4 m wide x 3 m deep and 0.5 m high) reentrant facing approximately southwest (around the corner from Cave I), in the south-facing slope of the ridge (Figure 55). There is a slight drip-line beneath the modern cave brow, and beyond the dripline the colluvial surface slopes steeply down to the Bluefish River. The strata exposed in the trench at Cave II also dip steeply (apparent at 42°) outward from the cave entrance.

The limestone ceiling and walls of the cave are heavily jointed, with macro-joint sets subdivided by numerous micro-joints providing easy access for moisture and acting to preform clasts prior to removal. Within the cave, approximately 1 m from the cave brow, the build-up of secondary carbonate precipitates is sufficient to provide a relatively smooth surface to the ceiling and walls. In places the calcite precipitate is sufficiently thick to obscure the jointing pattern. At the contact between the walls and accumulated sediment, extensive moss etches the wall rock and apparently inhibits the build-up of secondary carbonate deposits. The cliff face above the cave brow is not similarly coated with secondary carbonate accumulations. In all probability, the lack of secondary carbonate accumulations on the cliff face relates to the greater sunlight and lower moisture levels present there, rather than because of rapid weathering of the cliff face.

Most of the floor of the cave is moss-covered. Near the rear wall, rodent dung has accumulated to a thickness of several centimeters. During the summer of 1982, the recess at the rear of the cave had a several centimeter thick buildup of surface ice. These data suggest that the cave microenvironment is moist and, in the absence of direct insolation, relatively cool.

Lithostratigraphy

Two sediment sampling columns were employed, one directly beneath the cave brow and the other some distance outside the cave entrance. Beneath the cave brow there is a thick 1.2 m unit of silt-rich sediment and minor gravel (here referred to as the Loess Unit, after Cinq-Mars 1979), capped by a silt-rich, matrix-supported limestone gravel stratum, loess/rubble, and a thin surface organic-rich unit, the humus/rubble (Figure 56, Table 13). Sample numbers 7/6/83-1 thru 7/8/83-1 come from this sample column. Beyond the cave

brow, the organic rich units expand to over 1.5 m thickness and overlie a thinner silty stratum, the latter containing less gravel-sized clasts than beneath the cave brow. Sample numbers 7/9/83-1 through 7/12/83-4 come from this sample column. The organic-rich unit can be further subdivided (as per Cinq-Mar's description) into a number of distinct sedimentary units based on the percentage of gravel. However, these units are laterally non-extensive and were not traceable from one wall of the excavation to the other (that is, during the summer I visited the caves, as the intervening sediment had long since been removed).

Characteristics of the Sediment

Coarse Fraction

Texture, Morphology and Concretions

Clasts greater than 1 cm constitute more than 50% by weight in all the upper samples (Figure 57) in the sample columns studied (humus/rubble and mixed rubble/loess units). Coarse clast content decreases to minimal values (3.2-7.6%) in the lowermost loess samples. Clast size in the coarse fraction varies between 2.4 to 4.65 cm, with higher values in the upper samples and generally decreasing mean size in the lower loess/rubble samples.

Angular clasts constitute a significant portion of samples in only a few instances, though, for most samples, angular to subangular clasts comprise at least 50% of the sample. Rounded clasts are abundant in only a few samples, approaching 10% in the loess/rubble sample 7-2. Concretions are present on a significant portion of clasts (ca. 10-30%) from all samples that contained a significant proportion of clasts greater than 1 cm.

Considerable lateral as well as vertical variability exists in the samples taken from Cave II. The loess/rubble samples from sample column 2, taken outside the modern dripline, are significantly coarser textured than those within the dripline, attesting to the addition of coarse gravel clasts from the cliff-face above the cave. The mean size of these clasts outside the dripline are somewhat smaller (<4.0 cm), likely as a result of greater post-depositional size comminution beyond the dripline. The samples from sample column 2 are additionally more angular in the upper humus/rubble samples. Lack of sufficient sample size precludes comparison of roundness for the loess and loess/rubble samples.

Fine Fraction

Values for organic matter content vary considerably from sample column 1 to column 2, beyond the modern lip mound and outside the overhang at the entrance (Figure 58). Beyond the lip mound the organic matter content for most samples is over 20% and ranges to over 50%. Within the cave, organic matter values are around 20% for the upper humus/rubble units and somewhat lower (<10%) for the lower mixed loess and loess units.

For the loess/rubble and loess units, phi diameters range from 6.1 ϕ to 6.5 ϕ , in the range of medium to fine silt. Mean and median diameters for the humus/rubble samples are somewhat coarser, 4-5 ϕ , in the coarse silt range. Sorting values for all samples are poor to very poor, with significantly better sorting indicated for the lower loess samples. All loess samples contain over 61% silt by weight, with the lowermost samples from both sample columns yielding approximately 80% silt-sized clasts by weight.

The samples from column 2, taken outside the modern dripline, are significantly richer in organic matter than those from within the cave. This increased organic matter content relates to the greater access to sunlight during the growing season for sediments exposed outside the cave brow. Phi diameters of fine fraction samples both inside and outside the dripline are similar. The sorting of samples in the mixed loess/rubble units varies somewhat inside and outside the dripline. Samples taken from sample column 2 are in general more poorly sorted (though some data are missing from this column).

Diagenetic and post-depositional Processes

As noted for Cave I, there has also been post-depositional movement within sedimentary strata at Cave II. The primary evidence for lateral movement comes from several well-defined lobes of loess overlying humus/rubble sediment. These lobes imply soft-sediment flowage from higher elevations involving stratigraphically lower silt-rich layers flowing over the more organic and gravel rich strata.

Age and Sedimentation Rate of the Deposit

Morlan and Cinq-Mars (1982) report a single date for Cave II of $15,500 \pm 130$ yr BP (GSC-3053) on a *Mammuthus* scapula from the lower half of the loess unit beneath the dripline. Given the similarity to Cave I in lithologic characteristics and stratigraphic position, in addition to a similar Pleistocene faunal assemblage in the loess/loess/rubble units, this date appears to be correct.

Due to the large size of this scapula, and the lack of available provenience data, I assume a depth of approximately 1.3-1.5 cm for this date. Using this for a rough estimate, I calculate a rate of sedimentation of between 8.3 and 9.675 cm per 1000 years. Again, as was discussed for Cave I, the sedimentation rate for this shelter in all probability varied significantly from the lower to the upper deposits. I assume, in the absence of other data, that these rates are minima for the loess and loess/rubble units and a maximum for the overlying humus/rubble units.

CAVE III

Cave III is a small (ca. 5 m x 5 m) deep cave with a ceiling approximately 1.5 m above the modern sediment surface, a southeasterly orientation to the cave mouth and good exposure to sunlight. The wall and ceiling rock are dissected by major joints and micro-joints, most of which are infilled with secondary carbonates as are the ceiling and walls. Vegetation on the modern cave floor consists of mosses, grasses and *Dryas*.

Several loess-cored frost hummocks occur within the interior of the cave. Approximately 1.5 m in from beneath the cave brow, the loess is exposed at the surface. Samples at Cave III were taken from two sediment sampling columns. Sample column 1 (SCIII-1) is located approximately 1 m from the dripline beneath the cave brow, while column 2 is located approximately 1 m outside the modern dripline.

Lithostratigraphy

We can divide the lithostratigraphy of Cave III into three units (Figure 59, Table 14): (I) an upper humus and rubble unit, extending approximately 1 m within the cave; (II) a discontinuous unit, intermixing elements of the humus/rubble and the underlying unit containing abundant evidence of frozen-ground phenomena in the form of frost hummocks; and (III) a relatively thick unit of silt to silty clay containing rare limestone clasts.

Depositional Processes

The general features of sedimentation at Cave III are similar to those described for Caves I and II. Early in the history of the cave aeolian deposition of mostly silt-sized clasts predominated. Following cessation of abundant aeolian sedimentation, cryoclastic removal of clasts from the cave walls and ceilings as well as extensive weathering of the cave brow combined with a high turnover of organic materials to produce the upper humus/rubble unit.

The rate of mechanically dislodged spall production apparently varied a great deal from the entrance area (beneath the cave brow) to just over a meter within the cave where physical weathering was very limited.

Characteristics of the Sediment

Coarse Fraction

Texture, Morphology and Concretions

As seen in the other two sites, the coarse fraction dominates the sediment accumulation in the majority of samples at Cave III, reaching 80% by weight in at least one sample (Figure 60). The median and mean clast diameters vary between almost 4 and 6 cm with the majority of clasts falling below 7 cm in maximum dimension. The lowermost samples in all cases exhibit a smaller mean size than the upper samples.

Gravel-sized clasts from Cave III contain a significant proportion of subrounded and rounded clasts, exceeding subangular and angular clasts in all samples. However, the vast majority of clasts are subangular to subrounded with the latter predominating in most samples. Concretion-coated clasts were present in frequencies of up to almost 20% in 5 out of 9 samples.

Fine Fraction

Several fine fraction samples are missing from Cave III. Sediments were uniformly rich in organic matter, with surface units exceeding 25% by weight (Figure 61). The humus/rubble units exhibit a great deal of variation in the mean size of fine fraction sediments, ranging from 5 ϕ to 8 ϕ , in the range of medium to very fine silt. Mean size of the loess samples is consistent with others sites, falling in the range of medium silt. Sorting is considerably better in the loess units, however, it varies from poor to very poor for all samples. Only one sample, 17-2, from the loess/rubble was composed of more than 60% silt (though data from the two loess samples identified in the field are missing).

Diagenetic and post-depositional Processes

The presence of relatively abundant subrounded and rounded clasts argues for fairly intense post-depositional alteration of clasts. The presence of several frost hummocks argues for mechanical post-depositional rounding of the primary clasts. Frost hummocks apparently only form in the loess units, probably due to the sensitivity of these sediments to deformation.

DISCUSSION OF THE NORTHERN YUKON SITES

I will first compare and contrast the sedimentary products at the three cave sites. Following this, I will attempt to place the sediments within the regional stratigraphic framework (paleoclimatic/biostratigraphic) discussed earlier. Finally, I will point out instances in which the Bluefish Cave sedimentological data are at odds with the predictions derived from classical cave sedimentology reviewed in Chapters 1 and 2.

All of the sediment samples from upper Holocene levels in the caves consist dominantly of clasts greater than 1 cm (Figure 62). The mixed loess/rubble samples varied between ~20-50% coarse fraction by weight. The loess samples all consist of less than 10% coarse fraction. Mean size of sediment samples are also equivalent for correlative sedimentary samples. In all the caves, the loess/rubble and loess samples decrease in mean size from values exhibited in the upper humus/rubble samples (Figure 63).

I don't believe that the decrease in coarse fraction percentages of the loess-loess/rubble samples necessarily tells much about increased or decreased "cryoclastic" weathering during the time represented by these strata. As is the case with any percentage data, a decrease in the coarse fraction contribution to the sample can be explained by either a real decrease in the rate of coarse clast production, or by increases in the rate of introduction or production of the other two size fractions of each sample. The textural and mineralogical data suggest that at least a portion of the sediment from the loess/loess/rubble samples is allochthonous. Therefore, I believe it is more reasonable to explain the decreased coarse

fraction in terms of an earlier, more rapid deposition of aeolian fine sediment with decreasing values in the upper units.

The decrease in the mean size of coarse fraction clasts can be explained by two alternative hypotheses. The first is that clasts detached from the ceiling and walls of the caves were significantly smaller during earlier phases of the infilling, and increased in size during the mechanical breakdown of the walls during later periods. The second hypothesis is that the mean size of clasts detached was originally approximately the same, with post-depositional size reduction affecting the loess/rubble samples to a greater degree.

With respect to the first hypothesis, a change in the size of coarse clasts may be due to differences in the freeze-thaw regime through time, as suggested by the cave sedimentological literature. However, it is unlikely that the fissures and joints varied in size from earlier to later periods of deposition. As this factor appears to control the dislodgement of clasts in these sites, I believe this hypothesis is unlikely.

The second hypothesis is difficult to test. If clast reduction is an ongoing process at these sites, as suggested by the decrease in the size of clasts in stratigraphically lower samples, there should be a concomitant decrease in the total percentage of coarse fraction clasts and an increase in the B fraction.

Figure 64 presents scatter diagrams of the mean size of coarse fraction clasts versus the percentage of the coarse fraction. For sites in which there exists a significant number of samples, the correlation coefficients were relatively high, suggesting that as the rate of production of coarse fraction clasts increased, the mean size of the clasts produced also increased.

Roundness (Figure 65) was compared between sites using the roundness index of Madeyska (1982). These data suggest that Cave I samples contain clasts which generally exhibit more angular edges than do those in Cave II, and that the Cave III samples achieve maximum roundness for the three sites. The reasons for these differences are not immediately obvious, although there exist several possibilities.

Rounded clasts must represent clasts which achieved post-depositional rounding (Farrand 1975). Those subangular and subrounded clasts may have been rounded on exposed surfaces initially while still attached to the rock wall. Rounding while attached to the rock wall can only have been accomplished by solution weathering of exposed surfaces. Post-depositional rounding, on the other hand, could have resulted from either solution weathering or mechanical grinding due to either vertical or horizontal motion with the strata.

The bedrock composition and characteristics (i.e. jointing) are similar between the three caves. The primary difference between the three caves lies in aspect and wetness of the sites. Cave I, with a greater angularity index has a north-northeasterly orientation. Caves II and III are oriented towards south-southwest and southeast respectively. Wetness of the sites is more difficult to evaluate. Both Cave II and III have greater buildup of moss on the cave floor and walls, and Cave II has surface ice exposed in the rear of the cave. These data suggest that Cave I may be somewhat drier than Cave I, even though it potentially receives less insolation than the other two sites. Further data relevant to the amount of moisture comes from the buildup of secondary carbonate concretions and the presence of frost hummocks. Although clasts from Cave I exhibit secondary carbonate concretions, these features are less prominent than those from the other two caves (Figure 66). Additionally, there is a noticeably lower degree of secondary carbonate buildup on the ceilings and walls of Cave I. Finally, both Caves II and III exhibit greater evidence for frost hummocking in exposed sections. Given these data, it is most probable that the greater rounding of clasts from Cave II and III relates to increased moisture availability and, possibly, greater mechanical grinding of clasts.

Without additional isotopic dates or paleontological data, it is not possible rigorously to estimate the age of lithostratigraphic units at Bluefish Caves I, II and III. Currently dates and/or paleontological estimate are available only from Caves I and II. However, the

stratigraphic similarity between these sites makes it possible tentatively to correlate the sites.

It seems most probable that the loess, and portions of the loess/rubble units can be equated with the late Glacial Duvanny Yar Interval during which there was extensive aeolian deposition throughout eastern Beringia (Hopkins 1982). This correlation is strengthened by the palynological study from Cave I and the dated macrofaunal remains at both Cave I and II.

Based on the *Betula* pollen rise in sediments from Cave I, the loess/rubble units and portions of the humus/rubble units probably date to the early Holocene. The overlying humus/rubble units must then have formed during the mid to late Holocene.

A number of studies were cited earlier attesting to climatic change from the late Pleistocene into the early Holocene. This climatic change is not directly identifiable on the basis of changes in autochthonous sedimentary products at the Bluefish Caves. Primary evidence for climatic change comes from palynological investigations and the climatic change inferred from the introduction of great quantities of aeolian sediments in the loess and loess/rubble units.

It is perhaps not surprising that classical cave sedimentological techniques fail to detect this climatic change. The late Glacial/early Holocene climatic change is identified primarily on the basis of an inferred rise in summer temperatures which would not have greatly affected freeze-thaw weathering processes. On the other hand, if hydration weathering is significant at these sites, the early Holocene is believed to have experienced an increase in precipitation over late Glacial conditions.

In reviewing the sedimentary products and processes for the Northern Yukon sites a number of observations were made that do not fit well with the standard interpretative framework in classical cave sedimentology. These observations have to do with the rates of clast production in very cold climates, and the relationship between secondary carbonate precipitate build-up on clasts and regional climate. The general patterns of sedimentation will be reviewed below with special emphasis placed on these parameters.

Gravity fall sediments in the Yukon sites, as predicted from the premises of classical cave sedimentology, consist of fairly coarse-textured sedimentary units (ca. 40-80% >1 cm by weight), except where dominated by aeolian sediments. The rate of accumulation of clasts is, for at least these sites, relatively slow, particularly only a short distance within the caves where evidence for coarse clast deposition is virtually absent.

Traditionally, the buildup of secondary CaCO_3 is taken to indicate the presence of a moist, relatively mild climate. This is certainly not the case for the Bluefish caves. Recent studies elsewhere in the subarctic (northwestern Alaska) have documented the occurrence of secondary carbonate deposition (calcretes) in soils (Dijkmans et al. 1986), and the data suggest that carbonate deposition will take place anywhere carbonate rich groundwaters emerge into an environment where there exists a lower partial CO_2 pressure. It is possible that the large carbonate buildup within the caves relates to the local vegetation. Although not to my knowledge substantiated by other work, it is reasonable that the local flora, consisting of abundant mosses, lichens and other pioneering species, may cause a more rapid dissolution of limestone than occurs in more temperate climates. The dissolved CaCO_3 would then precipitate over the walls and ceilings of the caves. Combining more aggressive groundwaters with slower rates of clast production (from low moisture levels and infrequent freeze-thaw oscillations) the large buildup of secondary carbonates might be a reasonable expectation for these northern caves.

Karst processes, including dissolution and precipitation of carbonate minerals has been noted from a wide variety of environments, including high alpine environments in northern latitudes and in subglacial environments. As long as permafrost does not hinder subsurface water flow, and sufficient vegetation exists to produce CO_2 enriched aggressive groundwaters, karst processes will occur. It is also important to bear in mind that in jointed bedrock, carbonate precipitates may have formed on rock surfaces long before the clast was actually dislodged.

Chapter 7

Discussion and Comparison of Sites

In the preceding chapters mechanisms of site formation and the inferred influence of climatic variables (macro- and microclimatic variables) on sedimentation processes were discussed for individual sites. In this discussion, the attempt was made first to separate the influence of non-climatic (e.g. geomorphic, lithologic) variables from climatic ones. Only after removing probable non-climatic factors was the attempt made to infer the role of climate change through time in producing variability within the sediment accumulations. In this comparative chapter I will seek to briefly review the major conclusions from the sites discussed previously, and compare them in terms of the relationship between modern and recent climate on the one hand, and the nature of the sedimentary fill on the other.

PRYOR MOUNTAIN STUDY SITES

The Pryor Mountain study sites provide an opportunity to compare changes in sediment characteristics in caves and rockshelters along an altitudinal transect, one that implies at least gross climatic variation along the transect owing to adiabatic processes. In this sense then, the sites located in the high elevation portion of the transect are today, and were in all probability in the past, under a more rigorous climatic regime than sites in the mid and lower elevation portion of the study area. That is, False Cougar Cave and Cave Ann regularly experience a significantly shorter frost-free period, a lower mean annual temperature, and, in all likelihood, a significantly greater diurnal temperature variation than sites in the lower elevations.

Regardless of the modern climatic situation, the texture of the sediments does not vary along this altitudinal transect in terms of either increasing coarseness or mean clast size of the coarse fraction from lower to upper elevations. The coarsest deposits are found in the lowest member of the mid elevation sites - Big Lip Rockshelter. The sediments yielding the smallest contribution of coarse fraction are those of Cave Ann, located in the highest elevations within the study area.

In addition, greatest roundness values occur in False Cougar Cave sediments, a site with a local climate receiving less precipitation than the mid elevation sites. Conversely, few secondary CaCO_3 precipitates were evident in the False Cougar sediments although they were present in appreciable quantities in Crystalsin Cave - a site which occurs in a wet local climate, but is today a very dry cave.

It is most probable that site-specific factors override the influence of local climate in producing sediment variability between these sites. These factors include: bedrock structure and, less likely, lithology; movement of subsurface water and snowmelting; influence of local snowfields on cave microclimatology; orientation of the cave mouth with respect to insolation; aggressiveness of local subsurface waters; and the presence of a large quantity of organic matter in the fine fraction. Due to these site-specific factors, correlation between sites within the Pryor Mountains, and details of the geomorphic history of each site, was not possible. Correlation to external Holocene climatic schemes for the region was tentatively suggested for only two sites.

Both False Cougar Cave and Cave Ann are located in the high elevation, subalpine park and meadow community, marked by low mean annual temperature, and a short frost free season. However, given a similar local climate, there are striking differences between their sediment accumulations that are, in my opinion, due to local site-specific factors.

The entrance to Cave Ann is situated so that it receives solar radiation for only a short period at the end of the day. In addition, the cave mouth is small, opening out into a larger

cavern, most of which never receives direct solar radiation. Thus, for the same local climate, Cave Ann experiences less diurnal temperature variation and a lower mean annual temperature. The narrow entrance and upward sloping cave floor preclude abundant snow drifting. This factor, combined with apparently fewer ceiling joints, makes for a drier cavern both in terms of snow melt and subsurface water introduction from above. The dryness of the cave in turn enhanced Cave Ann's attractiveness to a variety of fauna whose byproducts make for a very organic rich sediment.

False Cougar Cave, on the other hand, is oriented so as to receive an appreciable amount of solar radiation, much of which strikes at least the south wall for a portion of the day. The cave is located within a prominent outcrop of rimrock which traps blowing snow causing False Cougar Cave to be inundated by an appreciable snowfill. This factor acts to insulate underlying sediments and to cool the cave walls and ceilings. The melting snow, combined with an appreciable introduction of subsurface water produces a continual wetting of the deposits once they have thawed. These "aggressive" waters, in conjunction with high moisture retention in organic rich sediments, in all likelihood are responsible for the diagenetic rounding of clasts within the deposit. The introduction of appreciable quantities of fine sediment through ceiling and wall joints also affected the coarse/fine ratio of sediment.

In addition to microclimatic factors, the False Cougar Cave fill contains abundant organic matter in the form of mammalian feces and carcasses as well as an indeterminable amount of vegetable matter. Research on the affect of humic acids and the variety of acids produced in rodent and avian dung and urine and associated microfaunal (lactic, acetic, oxalic) and floral agents (oxalic and citric) has illustrated that weathering processes are greatly accelerated on rocks covered by a humus versus those not covered (Chorley et al. 1984). It is likely that these sources had a significant effect upon the weathering of both clasts contained within the deposit and cave walls in contact with the sediment fill.

At the mid elevation, both Crystalsin Cave and Big Lip Rockshelter exhibit a great deal of sediment variation, little of which is explainable in terms of local macroclimate. The lower sediments in both caves (similar to False Cougar Cave), owe their deposition more to fluvial than colluvial processes and therefore say little directly about climate (though they are informative regarding the local geomorphic situation about the sites). The coarseness of deposits in Big Lip Rockshelter and Crystalsin is primarily a function of the coarse jointing in their respective walls and ceilings (note particularly the *eboulis sec* of Crystalsin Cave). At Big Lip Rockshelter the coarse jointing is readily available for exploitation by simple expansion of water on freezing. At Crystalsin Cave the apparent dryness of the cave would seem to argue against water as an important agent in the detachment of clasts from the walls and ceilings. In all likelihood, the major factor in clast detachment at Crystalsin cave was the expansion and growth of calcite crystals behind clast joints following degassing of carbonate rich groundwater. The angularity of the clasts argues for only small quantities of water but the coniferous vegetation above the shelter was probably important in producing a carbonate rich groundwater which over time dislodged the already jointed clasts below.

Big Lip Rockshelter, on the other hand, is beneath a sagebrush and grass slope and is probably less affected by this mechanism. Rather, although Big Lip Rockshelter is a wetter site than Crystalsin cave in terms of absolute quantities of water reaching the cave, most of the water entering Big Lip Rockshelter is wind driven precipitation or water entering the sloping limestone surface above, little charged with CO_2 due to the negligible soil cover, and therefore containing insignificant quantities of CaCO_3 .

The desert sites are predictably not comparable due to differences in lithology. In this case, the mechanism of salt growth and grain by grain detachment is less a function of annual temperature as it is temperature extremes and low moisture levels during the summer months.

SOUTHERN ALBERTA ROCKY MOUNTAIN SITES

Interestingly, although the sedimentary record at January Cave spans at least the mid-Wisconsinan non-glacial interval and the late Wisconsin Maximum through to the present, with abundant evidence of significant climatic change from other sources in the region, there exists virtually no textural or morphological evidence for a change in the patterns of sedimentation over this period. Racehorse Creek Rockshelter, on the other hand exhibits abundant evidence for variable texture of its sedimentary units. Although January Cave lies in a demonstrably more rigorous climate than Racehorse Creek Rockshelter, the latter has produced a coarser textured sediment (in terms of percent of sample >1 cm).

January Cave is located in a relatively moist, very cold climate, with marked seasonality and diurnal temperature variation. One would expect a coarse-textured colluvium to comprise the sediment fill at this site, as indeed litters much of the slopes above and below January Cave. The reasons for the apparently contradictory fill are most likely referable to the nature of the rock comprising the ceiling and walls of January Cave, in contrast to surrounding rock types which have produced a coarse, angular rubble. The bedrock comprising January Cave is an argillaceous, fossiliferous limestone. Both the wallrock and the clasts within the sedimentary fill are crumbly, easily comminuted rock.

Similar to False Cougar Cave and Cave Ann, January Cave was intensively occupied by a variety of mammals and served as a final resting place for their remains. The weak acids produced from the decomposition of this organic matter, and the waste products, combined with high moisture retention, have undoubtedly acted to reduce the final size of clasts within the deposit and to alter their morphology.

NORTHERN YUKON SITES

The three Northern Yukon sites yielded some of the coarsest textured deposits within the sites examined. This factor is in keeping with the demonstrably more rigorous climate surrounding these sites. The morphology of clasts is variable in terms of its consistency with dominant views of physical weathering. Clasts are more angular than those found in the more southerly sites. However, the Northern Yukon Caves produced clasts bearing abundant evidence of secondary carbonate precipitation, a feature not expected in these sites. These secondary deposits were also observed to coat the ceilings and walls of the sites.

The reasons for the apparent discrepancy between sedimentary products and local climate with respect to the classic interpretation of physical weathering must relate in part to the latitudinal factor. If the greatest degree of physical weathering takes place under conditions of frequent freezing and thawing, with temperature amplitude playing a more minor role, then the pattern of sedimentation at these shelters makes more sense. Throughout the long Yukon winters temperatures rarely exceed 0°C and throughout the short summers temperatures are largely above freezing. The period of frequent oscillations over the 0° isotherm is a relatively short during the spring and fall. The presence of permanently frozen ground beneath the floor of Cave II argues for a lack of thawing temperatures within the cave proper. Likely, this latter factor accounts for the shallow extent of the Northern Yukon Caves. With excavation, they quickly reach a depth where direct solar radiation no longer penetrates. Beyond this extent little further physical weathering of the cave walls and ceilings occurs as temperatures are below freezing for almost the entire year.

The presence of a thick coating of secondary carbonate precipitate on the walls and ceilings must relate to the slow physical weathering of clasts from the ceiling and walls and a rapid dissolution of the limestone above the shelters. I have already discussed the probable reasons for the slowness of physical weathering within the shelters, and the rapidity of chemical weathering must relate to the nature of the plant growth and possibly the aggressiveness of snowpack meltwater.

Comparisons of All Sites

Surface Samples

In the discussion to follow, the percentage of the A fraction in samples and the mean size of A fraction clasts are compared to macroclimatic variables (Table 15). Admittedly, for this study I have only a relatively crude estimate of the value of macroclimatic variables which may be significant in influencing the rate of physical weathering at these sites. Additionally, it is quite possible that other climatic variables than those used here are important in influencing the rate of physical weathering in a cave. However for two reasons I feel it appropriate to compare variables of sediment texture to the climatic variables presented here.

In the first place, the literature from the physical weathering field, both laboratory and field studies, show no agreement on which climatic variables are important. Secondly, the variables used here closely approximate the reconstructions of climate traditionally used in cave sedimentological research.

Figure 69 presents plots of the weight percent of the coarse fraction in surface sedimentary units against three climatic variables (annual frost free days, mean January temperature, and mean annual temperature). Simplistically applying cave sedimentological interpretive principles, the sites experiencing a lower mean annual temperature, lower January temperature and fewer frost free days should yield a coarser sediment, i.e. a greater contribution of the A fraction to the sample. These scatterdiagrams, on the contrary, show that Big Lip Rockshelter, with a "warmer" climate has a greater percentage A fraction than any of the other sites. Even holding the bedrock variable constant, Big Lip Rockshelter has a coarser A fraction in the surface samples than other Pryor Mountain sites at higher elevation (e.g. False Cougar Cave and Cave Ann).

The variation in mean clast size of the surface samples from all sites is plotted against the three climatic variables in Figure 70. This variable also fails to correlate in a positive fashion with increasing rigor of the local climate as measured by these variables. The values from Racehorse Creek Rockshelter may possibly be excluded, due to the very different lithologic makeup.

The variation in mean clast size and percent A fraction is plotted against mean annual precipitation in Figure 71. Again, as with the other climatic variables, there is no apparent correlation between increasing precipitation and clast size or coarseness of the sample. The scatterdiagrams indicate that, for these sites at least, other factors, more complex than the simple macroclimatic variables shown here are the dominant controls determining the texture of sediment units in these sites.

Figure 72 is a scatterplot of the mean clast size vs. percentage sample greater than 1 cm in size for all sites. It has been suggested that this relationship should correlate highly, with greater values of each parameter indicating a progressively more rigorous climatic regime (Laville et al. 1980). Such a relationship is not indicated in Figure 72, which plots the relevant values for all sites investigated in this study (excepting the two desert sites in the Pryor Mountain study area). If, in fact, either of these two variables reliably predicted climate of formation of a sedimentary unit, then the fact that they do not correlate highly suggests that interpretations based upon them would be misleading.

Perhaps the greatest deviation in sediment parameters for sites discussed in this study from the predictions of classical cave sedimentology come from values for clast morphology. Figure 73 presents values for the rounding index, as calculated from the formula in Madeyska (1982). The values presented in this diagram are approximately reverse from what would be predicted from a simple examination of the local climates under which the sediments formed. The Yukon caves exhibit relatively high roundness index values (indicating a large number of subrounded and rounded clasts), though the local climate is very cold, and semi-arid. The Pryor Mountain sites exhibit increased roundness values in accordance with increased precipitation at higher elevations though the

increased roundness index values also correlate positively with decreased temperature at higher elevations.

Variation in Late Quaternary Sediments

The chronological controls on strata discussed here are inadequate to compare strata which formed during specific time periods of the past. Additionally, it is difficult to quantify late Quaternary climates which may have affected sedimentation in these caves and rockshelters. It is possible, however, to compare the variability in textural parameters of samples taken from late Quaternary deposits. These data will provide information concerning the dispersion of values of textural parameters from these sites. Statistical measures of dispersion for sites discussed in this study are presented in table form in Tables 16 and 17 and graphically in Figures 74, 75 and 76.

The least dispersion around mean values occurs in samples from the Yukon (Caves I-III) and Big Lip Rockshelter. The greatest dispersion occurs in samples from Crystalsin Cave, January Cave and Cave Ann. The explanation for the greater dispersion in values from these latter sites is not immediately apparent though almost certainly has little to do with regional climate change as other nearby sites were not similarly affected. Rather, I would suspect that the greater variation has to do with changing processes of sediment introduction through time and, for January Cave, progressive size reduction of clasts through time.

Rates of Sedimentation

There are several reasons making it difficult to accurately estimate the rates of sedimentation under which sediments accumulated in a given cave or rockshelter. In this study the paucity of ^{14}C dated samples make any estimates very crude. Additionally, when estimating sedimentation rates based on linear extrapolations between radiometrically-dated samples several tenuous assumptions must be made. One must first assume that sediment was not removed by erosive processes while the sediments were accumulating. One must also assume that sediment accumulated gradually and in a linear fashion rather than during periods of rapid sedimentation amid other periods of relatively slow sedimentation. Differences in the volume of the sites is also certain to affect estimated sedimentation rates as in smaller caves the walls of the shelter will also contribute sediment to samples while in larger caves in samples taken some distance from the wall only the ceiling will yield sediment. A further difficulty arises when comparisons of estimated rates of sedimentation are made between sites that received sediment from diverse vectors. For example, in comparing the caves reported in this study to those from the Paleolithic of southwestern France, it is abundantly clear that humans played a major role in the accumulation of sediments in France whereas their influence was minimal to absent in the sites reported here. Given all these difficulties, one must approach estimated sedimentation rates and their comparison between sites with extreme caution.

Radiocarbon dated estimates of average sedimentation rate were calculated for Crystalsin Cave, Big Lip Rockshelter and False Cougar Cave to be between 13 and 17 cm 1000^{-1} years (Table 18). As discussed in Chapter 6, estimated maximum average sedimentation rates for the Bluefish Caves are similar to those in the Pryor Mountains, with a crude estimate of between 15 and 10 cm 1000^{-1} years. The estimated average annual sedimentation rate for January Cave is extremely low, certainly less than 5 cm 1000^{-1} years if the radiocarbon date is accepted and a maximum of approximately 15 cm 1000^{-1} years if an age of ca. 10,000 years is used on the basis of included Pleistocene fauna. The single radiocarbon date from Racehorse Creek Rockshelter provides an estimated average sedimentation rate of 16 cm 1000^{-1} years for at least the last 3000 years at this site.

Table 18 lists the estimated average sedimentation rates for sites discussed in previous chapters. Column two presents sedimentation rates based on radiocarbon dates. The figure in parenthesis indicates the time span over which the estimated sedimentation rates

are applicable, based on the lowermost C^{14} sample used in the calculation. Sedimentation rates in column three are estimates of the maximum possible sedimentation rate assuming a minimum date for inception of sedimentation and the thickness of the sediment column above bedrock. The minimum age estimates are based on paleontological or paleobotanical data where possible (Bluefish Caves, January Cave).

Although the sedimentation rates for several of the sites presented in Table 18 are perhaps several magnitudes too high, and the others certainly span periods of more or less rapid sedimentation, the values are surprising for the extremely low rate of sedimentation, in comparison with the few other sites where data are available. Farrand (1975) calculated the sedimentation rate for sections of strata and an average sedimentation rate for the Abri Pataud, an Upper Paleolithic rockshelter in the Périgord spanning ca. 34,000 to 22,000 yrs BP. Maximum sedimentation rates were approximately $182 \text{ cm } 1000^{-1}$ years and minimum rates were $55 \text{ cm } 1000^{-1}$ years. The average sedimentation rate was calculated at $100 \text{ cm } 1000^{-1}$ years. Very few other rockshelter sites exist for which there is sufficient information to calculate sedimentation rates. By visual examination of section profiles and the approximate position of C^{14} samples, I calculated a crude approximation of the sedimentation rate for Pont d'Ambon and Flageolet II, presented in Laville et al. (1980). The Upper Paleolithic through Azilian levels at Pont d'Ambon produced a sedimentation rate of $25 \text{ cm } 1000^{-1}$ years. The late Pleistocene, Upper Paleolithic sediments at Flageolet II yielded a rate of $46 \text{ cm } 1000^{-1}$ years.

Harris (1988) compiled data on the rate of rock face retreat under cold climate for the few sites where data exist. Measured rates of rock retreat vary from a minimum of between $0.003\text{--}0.019 \text{ mm yr}^{-1}$ in an arctic alpine environment (Ogilvie-Wernecke Mountains, Yukon; Gray 1973) and a maximum of 2.5 mm yr^{-1} under maritime, alpine conditions in the Swiss Alps (Barsch 1977). Other measured rates include $.3 \text{ mm yr}^{-1}$ in Spitsbergen (maritime, arctic; Jahn 1976) and between 0.06 and 0.26 mm yr^{-1} in Jasper National Park (Luckman 1976).

Assuming these values were similar to weathering rates in caves and rockshelters, portions of a shelter receiving sediment only from the ceiling (far enough from the walls) would receive between 0.3 and 1.9 cm and $250 \text{ cm } 1000^{-1}$ years of clastic sediment. Excluding these two maximum and minimum values, the intermediate values of between 26 and $30 \text{ cm } 1000^{-1}$ years are somewhat higher than values reported in this study, and significantly lower than reported from Pleistocene sites in southwestern France, where maximum rates of sedimentation were almost 5 times higher.

It may be reasonable to expect higher rates of weathering in exposed situations, as reported in the studies cited by Harris (1988). However, though the sites discussed in this study are located in more sheltered microenvironments, in addition to clasts weathered off the ceiling they, 1) receive additional material from the walls (which in small shelters might triple the potential source area for clastic debris), and 2) receive additional material from sources exterior to the site.

It is probably not advisable to compare inferred rates of rockwall weathering between caves and rockshelters on the one hand, and exposed rock walls on the other. It is however, useful to examine the pattern of changing rates reported from sites located in different climatic zones.

As predicted from experimental physical weathering research, maximal rates of weathering occur under maritime alpine and arctic conditions. Minimal values occur in continental arctic and alpine climates. Although studies are limited, these data support experimental research in assigning moisture the dominant role in determining rates of physical weathering. It is perhaps surprising, however, that the lowest values are reported from one of the colder climates, in the Yukon territories.

As reviewed earlier, the sites discussed in this study follow a pattern similar to the studies reviewed by Harris (1988). The Bluefish Caves, although only a very crude

estimate for the sedimentation could be calculated, exhibited very slow rates of sedimentation. Highest rates were inferred for the mid elevation sites in the Pryor Mountains.

Discussion of the Problem

It was noted in Chapter 2 that field and laboratory studies of physical weathering phenomena have not yet yielded clear interpretative rules such that the texture or morphology of sediments could readily be equated with variables of temperature and moisture. However, assuming that such causative rules were available, it is still unlikely that these same features of a sedimentary deposit could be related to changes in regional climate. The reasons for this have to do with the myriad ways in which sediment can be introduced, or removed from a deposit and the influence of regional macroclimate on the temperature and moisture affecting the ceiling and walls of a given shelter.

In order to reconstruct regional climate from changes in the texture and morphology of sediments one must first understand the rates of various geomorphic processes and the varied vectors under which the processes may operate. Additionally, the controls on these rates and processes are certainly not "regional climate". A number of the processes operate essentially independently of regional climate (or at least in such a way that it would be impossible to directly link them to regional climate) and for other process or rates, the influence of regional climate is filtered through a series of intermediary factors, some of which may be determined after the fact and others for which this is impossible.

The factors which determine the textural and morphological characteristics of a sequence of strata in a cave or rockshelter are varied. In the broadest sense the rate at which any of three processes affect the site will determine the ultimate sediment composition of the site. These rates are:

- 1) the rate at which various sediment sizes are introduced into the depositional site
- 2) the rate at which various sediment sizes are removed from the site
- 3) the rate at which various diagenetic processes affect various portions of the strata

In order to reconstruct the depositional and diagenetic history of a sedimentary package the behavior of these rates over time must be understood. The difficulty with this goal lies in the fact that one must necessarily assume a linearity in the rate over the span of a homogeneous sedimentary unit while in fact there is every possibility, and even likelihood, that rates are not linear over time. Let us examine these rates in more detail and look at their contribution to the construction of a hypothetical sedimentary unit.

The texture of a sedimentary unit, i.e. the size and sorting of clasts, will depend upon the rate/s at which various sediment sizes (gravel-sand-silt-clay) are introduced into the site (by a variety of vectors as discussed in Chapter 3), the rate/s at which these sediment sizes are selectively, or randomly, removed from the site by erosive processes, and the rate/s at which diagenetic processes reduce the size of clasts over time. Different combinations of the three rates could potentially yield an identical sedimentary deposit. For example, production of an *éboulis sec* (coarse, clast-supported deposit) could arise from any of three possible scenarios involving different rates of sedimentation, erosion and diagenesis. The development of a coarse, clast-supported sedimentary deposit requires, 1) that the rate of introduction of gravel-sized clasts be extremely rapid over a short time period, far exceeding the rate of production of matrix-sized clasts; or 2) that the rate of production of gravel-sized clasts be constant over a longer time period and the rate of introduction of matrix-sized clasts (sand, silt, clay) be very low, or 3) that the rates of production of coarse clasts and matrix clasts be relatively constant while the removal of matrix fines proceed at

rates rapid enough that these materials are removed prior to sealing of the deposit by overlying sediment.

The rates of production and/or introduction of various sediment sizes to a cave or rockshelter may be linked to climate, for example, the disaggregation of ceiling rock by freezing water or totally unrelated to climate, for example, the selection of a site as a long-term habitation by groups of hunter-gatherers. Even where the sediment production is at least influenced by climate, it is not necessarily regional climate that affects the rate of production. Rather, in the example just given, the rate of freeze-thaw weathering would depend upon bedrock temperature fluctuations and moisture in contact with the freezing site rather than gross regional climate.

Chapter 8

Conclusion

The goal in cave sedimentological studies is to reconstruct regional climate by detecting changes in the mineralogy, texture, and morphology of sediments resulting from changes in physical weathering rates (closed system approach) or changes in local geomorphic rates (open system approach). In order for these methods to produce valid results there must be a demonstrable link between regional climate and those processes whereby sediment accumulates in a cave or rockshelter. This dissertation has attempted to test some of the major assumptions used by cave sedimentologist to reconstruct past regional climate by virtue of changes in the texture of sediments. Although the conclusions from this study are weakened by a lack of truly accurate estimates of climatic variables and tight chronological control, it seems evident that gross climatic differences between sites discussed in this study are not discernable through examination of the sediments contained within them.

It is perhaps not surprising that gross regional climatic differences between sites have not left a readily discernable imprint on the texture and morphology of the sediments discussed here. For a number of theoretical reasons, it is perhaps to be expected that variables of regional climate would not be the major factor producing variability in sediment parameters. In the first place, our understanding of the important variables promoting physical weathering are, at present, only poorly understood. Secondly, variation in the rate of physical weathering of a shelter is only one of the variables affecting the rate whereby sediment is introduced into a site. As discussed in Chapter 3 and illustrated again in Figure 76, sediment is introduced into sites by a variety of vectors, many of which are not directly influenced by regional climate. Thirdly, as illustrated graphically in Figure 76, the influence of regional climate on the rate of physical weathering at a site is surely filtered, depending upon local microclimate and the characteristics of the bedrock.

Evaluation of the Cave Sedimentological Model

The present work has important implications for classical cave sedimentological interpretations. It suggests that macro- or regional climate is not the major factor controlling the composition of sedimentary fills in cave and rockshelter entrance facies for these sites analyzed in this study. In particular, other things not being equal, the coarseness of a sedimentary fill will not necessarily vary in a positive fashion with increasing temperature on an intersite basis. The reasons for this discrepancy have to do with cave microclimatic conditions, the nature and structure of the host rock, and non-climatically linked sources of sediment. Thus texture of cave sediments is not an unambiguous indicator of the climate under which the sediments accumulated.

Additionally, other, oft-cited indicators of particular climatic regimes were shown to occur under a wide variety of conditions. Secondary carbonate coatings, used to indicate a warm, temperate climate, were found coating clasts above 2000 m in the Pryor Mountains and, more suprisingly, on gravel-sized clasts in the Northern Yukon, within the zone of continuous permafrost (where it is today apparently an on-going process)! These data suggest that secondary carbonate coatings will occur anywhere CaCO_3 enriched groundwater emerges from cave walls and ceilings, irrespective of local climate.

Furthermore, clast morphology, particularly roundness and shape (*plaquettes du gel*) were not seen to be useful climatic indicators. Rounded clasts were identified in virtually all samples, though the angularity of clasts in the Yukon sites was generally greater. In the altitudinal transect, great differences were identified between the two high altitude sites,

under similar macro-climatic conditions, while sites at lower elevations exhibited greater angularity of clasts (Big Lip Rockshelter and Crystalsin Cave).

Nowhere were tabular clasts, believed to be indicators of extremely low temperature, identified except for Bluefish Cave I, where the structure of a particular bed of the host rock is responsible for their production. The reasons for the lack of this particular clast morphology are unclear. The experimental work of Lautridou (1988) suggests that tabular fragments should result from temperatures below 10° C over long duration, as would be expected for the Bluefish Caves and the high altitude Pryor Mountain sites.

Evaluation

The evaluation of any scientific method, or procedure, ultimately lies in its utility for answering the questions for which it was designed. The question is then, whether or not the methods of cave sedimentology provide a means to, reconstruct unambiguously the regional climate under which the sediments accumulated so as to provide a means of intersite correlation. An unqualified "yea" can only be made if: (1) our understanding of physical and chemical weathering processes enables us to predict the output, in terms of sedimentary products, from rock weathering under a specific array of regional climatic variables; (2) the sum influence of microclimatic factors and other features intrinsic to the site do not mask variation in regional climate; and (3) quantitative and qualitative analytical methods are sufficiently precise to reconstruct unambiguously the climate of formation of a specific sediment accumulation.

The current state of uncertainty in the field of physical weathering research makes it certain that we cannot predict the output unambiguously, in terms of weathering products, of a specific rock type from a given input of regional climatic variables. It is currently impossible to infer the role played by hydration weathering above 0° C versus freezing related phenomena below 0° C. Furthermore, as the actual mechanism of rock breakdown below 0° C is unclear at present, it is impossible to predict the response of a given rock type to variable freeze-thaw conditions, such as intensity, duration, and frequency of freeze-thaw.

Secondly, the present study has shown how microclimatic factors and features intrinsic to a particular site may "mask" the effect of regional climate, producing variable sedimentary accumulations under similar regional climatic conditions. Site specific factors are clearly recognized by cave sedimentologists; "Sediments representing any given climatic oscillation are never precisely the same from one site to the next." (Laville et al. 1980: 133). However, it is ultimately believed that those factors intrinsic to the particular conditions or history of a specific site can be factored out, permitting intra- and/or interregional correlation of sedimentary strata. Within the sediments constituting a particular stadial block, as outlined by unconformities (discussed below), sediments are correlated partly by similarity in stratigraphic position and by the "artisans touch, the professional's 'feel' for empirical data." (Laville et al. 1980: 134).

It might be useful at this point to draw an analogy from palynological methods and interpretations. It is currently widely recognized by palynologists that fluctuations in the percentages or absolute pollen influx at particular sites are not immediately interpretable in terms of changing climate, even for taxa that are sensitive to changes in climate (Birks and Birks 1980). Factors intrinsic to the particular site, or having to do with differential dispersal rates, edaphic factors, or disease may affect changing pollen values at sites. Thus non-climatic factors must first be ruled out before an inferred change in climate can be made.

Similarly, the climate of formation of a cave or rockshelter is inferred from the characteristics of texture, morphology and geochemistry of the sediments. That the climatic inference is not unambiguous follows from the uncertainty regarding mechanisms of clast disaggregation under various climatic conditions of temperature and humidity. Further ambiguity is added due to the potentially different responses of different bedrock types to

climatic variables and variable microclimatic or geomorphic variables as have been discussed in this study.

Unconformities indicating interglacial/interstadial

No situations analogous to those reconstructed for southern France, where interstadial/interglacial climates are defined on the basis of unconformities (i.e. eroded soils), were examined in this study. However, the importance of unconformities to the French method of constructing and correlating regional paleoclimatostratigraphic sequences makes some discussion necessary.

In the climatostratigraphic scheme outlined by Laville et al. (1980), "glacial" climates producing coarse clastic deposits are regularly replaced by interglacial/interstadial climates. The climatic amelioration associated with these nonglacial climates results in formation of thick soils characterized by illuvial clay in the B horizon. In every instance where paleosols have been identified, the "soil" is truncated with only a portion of the B horizon remaining. Thus, truncation of the A and the upper portion of the B horizon is believed to result from erosion by running water, immediately before the onset of the next glacial episode.

At least one other author (Goldberg 1979) has questioned the validity of this scheme by his inability to find independent, micromorphological evidence for pedogenic processes in the "soils" identified by Laville and others primarily on textural grounds. It has often bothered me, viewing the Perigordian rockshelters from a strictly geomorphological standpoint, how runoff should necessarily be channeled into these rockshelters preceding an oncoming glacial climate. If the primary variables controlling the rate of erosion on a particular segment of the earth's surface are reasonably viewed as nature and intensity of precipitation, slope, and vegetation cover, it is difficult to see how any of these variables should change significantly in a relatively protected rockshelter environment. If the runoff is introduced into the shelter from outside, the converse would be more likely, where sediment eroded from possibly less well vegetated slopes surrounding the shelter is mobilized into the shelter.

Unfortunately, if the key (in the form of unconformities in shelter sediments) is removed, the remainder of the paleoclimatostratigraphic scheme, and certainly intersite correlations must fall. This then places in great jeopardy our understanding of the chronology of the various Paleolithic assemblages defined for that region. The only remedy would seem to lie in obtaining a greater number of absolute dates for these sites.

Given the conclusions presented in this thesis, as well as the theoretical weaknesses in the French paleoclimatic scheme, it is perhaps wiser to abandon the idea of climatostratigraphic units, as recommended in the publication of the American Commission on Stratigraphic nomenclature (ACSN 1983). At present the theoretical basis for understanding the physical disaggregation of rock surfaces by various combinations of temperature and moisture is poorly understood (cf. Thorn 1988). Certainly we must also call into question many of the primary assumptions behind the reconstruction of climate from rockshelter sites, as suggested by the data here. So, if the ability to reconstruct past climates is ambiguous, the correlation of sedimentary strata from one site to another, or to more widespread climatic records, is dubious. The extrapolation to other climatic records is equally shaky whether using the open- or closed system approaches as defined in this study.

COMMENTS REGARDING FIELD METHODOLOGY

Throughout this dissertation, the characteristics of sedimentary strata have been described based on the removal of very large, bulk sediment samples from archaeological exposures. This methodology is standard for most cave sedimentological research (see however Butzer 1981). Based on the conclusions from this study and my field experiences

(carrying a pack filled with three >20 kg sediment samples for distances up to 3 km), I would suggest abandonment of large sediment sample removal.

It is certain that quantitative comparisons of the coarseness of sedimentary units cannot be used as a means of correlation (in either a climatostratigraphic or chronostratigraphic sense) between caves and rockshelters even within the same local geographic area. Additionally, it is questionable whether very small variations in the fraction of a sample containing clast sizes larger than 1 cm are statistically valid when an upper limit of 10 cm is used. I believe that qualitative field descriptions are probably accurate enough in distinguishing large differences in clast content of clasts greater than 1 cm. Relying on field estimations of coarse clast content would greatly speed up the sedimentologists' work as well as decreasing interference with archaeological operations and drastically decrease the amount of destruction of the site.

Samples of the fine fraction could then rely on smaller sediment volumes. Clast morphology or the quantitative estimation of the presence of secondary carbonate concretions could be quickly and easily performed by counts in the field of a representative number of clasts. These measures would in no way affect the statistical significance of a study and would have all the advantages of decreasing lab time and destruction of exposures in the field.

SUGGESTIONS FOR FUTURE RESEARCH

One of the major conclusions of this paper is that not enough is known about the mechanics of clastic sedimentation in caves and rockshelters to produce reliable climatic interpretations using properties of the sediments alone. Particularly, the construction of detailed microstratigraphic columns, correlated between sites within a region and to climatostratigraphic schemes outside the region, anchored by very few radiometric dates, is a questionable undertaking. I believe this admonition is equally valid for cave sedimentological studies exemplified in the work of Laville or Butzer, my two examples of the closed and open cave systems. Laville's work (e.g. Laville 1975) suffers primarily from the mechanical application of an interpretive system, lacking in a geomorphic perspective, and the forcing of the results into a now largely discredited Alpine Glacial stratigraphic sequence. Butzer's work (e.g. Butzer 1981, Butzer et al. 1978), although incorporating a geomorphic perspective, places great reliance upon the tenuous link between the cave as a sediment trap and vegetative changes outside the cave system. More serious, in my opinion (an opinion not shared by everyone), is the subsequent forcing of this climatostratigraphic scheme into the marine O^{18}/O^{16} global stratigraphic scheme. While the latter scheme appears to have global applicability, the correlation from the marine to the terrestrial record is, and probably always will be, fraught with difficulty. We are only fooling ourselves to believe that correlation from our own tenuous climatic constructions to a more objective one elsewhere enhances the validity of our own constructions. In this case all we have done is substitute one dubious correlation (to the Penck/Bruckner system) for another (the marine system), not advancing our understanding of local or extralocal climatic change in either case. Geologists are not alone in this propensity to correlate to a seemingly lawlike sequence as witnessed by the recent study of the European Paleolithic by Gamble (1986).

Certainly it is important to continue reporting in some detail the sedimentological characteristics of cave and rockshelter sections from a variety of microclimates. This study only scratches the surface of a complex issue, and is limited to only a few gross climatic types. What we urgently need is a systematic presentation of rockshelter sediments from more temperate areas. Unfortunately, with the advent of radiocarbon dating, archaeologists are largely content to date their included assemblages with absolute dates and neglect a detailed discussion of Holocene sediment packages.

The most pressing need for further research lies within the realm of understanding the mechanics behind the physical weathering of limestone caves and rockshelters. The

uncertainty among specialists regarding the primary agent, whether hydration, expansion of water, or any of the many other hypotheses, makes it impossible to assign a particular climatic variable to the production of particular kinds of sedimentary products. Until this basic research is carried out, the classical cave sedimentology exemplified by Laville and others, as well as the interpretations contained within this dissertation, will be suspect.

Table 1

Climatic interpretation of textural and morphological features
in cave and rockshelter fills

Textural and Structural	Climate
Clast-supported +/- matrix	cold and dry
Matrix-supported	cool
Matrix-supported; few clasts > 1cm	temperate
Soliflucted (recognized by either sedimentary structures or morphology of clasts)	cold (beginning or end of stadial)
Fluvial	temperate
Unconformity - irregular erosional boundary; illuvial clay below	temperate
Morphology of Clasts	
Angular	dry (+/- post-depositional)
Rounded	temperate, humid
Blunting (without increased porosity)	very cold (cryoturbation)
<i>plaquettes de gel</i> (frost slabs)	very cold
<i>cailloux gélivés</i> (frost-cracked rocks)	cold (post-depositional)
<i>cailloux fissurés</i> (fissured rocks)	cool

(The climatic interpretation of particular textural or morphological evidence presented in this table has been abstracted from the discussion in Laville et al. 1980).

Table 2

Proposed mechanisms of physical weathering

Mechanism	Reference
Volumetric expansion of water -	Battle 1960; Lautridou 1971, 1976; Mellor 1970, Martini 1967; Wiman 1963; Potts 1970; Guillien and Lautridou 1970.
Crystallization pressure of ice -	Connel and Tombs 1971
Crystallization of salts -	Cooke (1979); Cooke and Smalley (1968); Evans 1970; Fahey (1986); Williams and Robinson 1981; McGreevy and Smith (1982);
Ice lensing hypothesis	Taber 1950; Mellor 1970; Everett 1961; Honeyborne and Harris 1958, Hallet 1983; Walder and Hallet 1985, 1986
Ordered water hypothesis -	Dunn and Hudec 1966; Hudec 1973, Fahey and Dagesse 1984
Hydraulic pressure hypothesis -	Powers 1945; Lautridou and Ozouf 1982

Table 3

Caves and Rockshelters Examined in this Study

Site	Lat./Long.	Elevation	Bedrock	Aspect	Size (w x d x h)
Bluefish Cave I	67°09'N/141°45'W	600m	EP ls	N	3.0 x 4.0 x 3.5
Bluefish Cave II	67°09'N/141°45'W	600m	EP ls	SW	4.0 x 3.0 x 0.5
Bluefish Cave III	67°09'N/141°45'W	600m	EP ls	SE	5.0 x 5.0 x 1.5
January Cave	50°11'N/114°31'W	1377m	MI ls	W	6.0 x 19.0 x 3.0
Racehorse Creek	49°46'N/114°27'W	1695m	Cc vol.	SE	3.0 x 2.0 x 2.5
False Cougar	45°10'N/108°21'W	2600m	Min ls	SE	3.0 x 3.5 x 1.0
Cave Ann	45°09'N/108°18'W	2566m	Min ls	SW	3.3 x 20.0 x 1.5
Crystalson Cave	45°08'N/108°25'W	1828m	Min ls	SW	16 x 12.0 x 10.0
Big Lip	45°08'N/108°26'W	1847m	Min ls	S	9.6 x 5.0 x 2.5
Beyond Level	45°06'N/108°37'W	1492m	Pt ss	SW	6.8 x 6.5 x 2.3
Shallow Promise	45°06'N/108°36'W	1501m	Pt ss	SE	3.4 x 1.5 x 1.2

Cc = Cretaceous Crowstnest Formation

Pt = Pennsylvanian Tensleep Sandstone

MI = Mississippian Livingston Formation

Min = Mississippian Madison Group

EP = Early Paleozoic, limestone

Table 4

Formulas for Grain size statistics used in this study (after Folk 1980)

Median(percentile; mm)	(Md _{mm})	P50	
Median (percentile; phi)	(Md _(φ))	φ50	
Mean (percentile; mm)	(Mz _(mm))	$\frac{P25 + P75}{2}$	
Mean (Graphic Mean)	(Mz _(φ))	$\frac{\phi16 + \phi50 + \phi84}{3}$	
Sorting (Inclusive Graphic Standard Deviation)	(σ ₁)	$\frac{\phi84 - \phi16}{4} + \frac{\phi95 - \phi5}{6.6}$	
		<0.35φ	very well sorted
		0.35 - 0.50φ	well sorted
		0.50 - 0.71φ	moderately well sorted
		0.71 - 1.0φ	moderately sorted
		1.0 - 2.0φ	poorly sorted
		2.0 - 4.0φ	very poorly sorted
		>4.0φ	extremely poorly sorted
Inclusive Graphic Skewness	(Sk ₁)	$\frac{\phi15 + \phi84 - 2\phi50}{2(\phi84 - \phi16)} + \frac{\phi5 + \phi95 - 2\phi50}{2(\phi95 - \phi5)}$	
		+1.0 - +0.3	very fine skewed
		+0.3 - +0.1	fine-skewed
		+0.1 - -0.1	near symmetrical
		-0.1 - -0.3	coarse skewed
		-0.3 - -1.0	very coarse skewed
Graphic Kurtosis	(K _G)	$\frac{\phi95 - \phi5}{2.44(\phi75 - \phi25)}$	
		<0.67	very platykurtic
		0.67 - 0.90	platykurtic
		0.90 - 1.11	mesokurtic
		1.11 - 1.50	leptokurtic
		1.50 - 3.00	very leptokurtic
		>3.00	extremely leptokurtic

Table 5
False Cougar Cave Lithostratigraphic Unit Descriptions

Unit	Thickness (cm)	Description
I	130-155	Abundant matrix supported, predominantly subrounded to subangular limestone gravel in generally organic rich, sandy, silty clay. This large unit was subdivided on the basis of variable organic matter content, and clast content. Lithostratigraphic unit designation was generally clear within the cave but beneath the cave brow, all units lost coherence. The infrequent platy limestone clasts exhibit generally horizontal orientations within the cave but exhibit vertical to plunging orientations in the confused area beneath the cave brow.
A	13-22	Subrounded to subangular limestone gravel (Mz=5.5cm) in a matrix of dark brown (10YR3/3), organic rich (14.8%), loose, friable, very poorly sorted sandy, silty clay. Nondegraded organic matter in the form of uncharred bones, plant remains and dung are present. No coherent charcoal lenses occur though charcoal is locally abundant in the form of dispersed charcoal.
B	23-32	Subrounded to subangular limestone gravel (Mz=5.95cm) in a matrix of very dark grayish brown (10YR3/2), organic rich (9.25%), soft, granular, very poorly sorted, sandy silty clay. Macroscopic plant remains or dung were not noted, though uncharred bones and scattered charcoal flecks and chunks were present. The upper boundary to Unit IA is clear and smooth.
C	14-24	Subrounded to subangular limestone gravel (Mz=5.45cm) in a matrix of dark brown (10YR3/3), organic rich (12.2%), soft, granular, very poorly sorted, clayey silt. The upper boundary to Unit IB is clear and wavy.
D	3-18	Subrounded to rounded limestone gravel (Mz=5cm) in a matrix of very dark grayish brown (10YR3/3), organic rich (14.6%), soft, granular, very poorly sorted, sand silty clay. The upper boundary to Unit IC is sharp and smooth, marked by a lense of charcoal.
D1	23-44	Subrounded to rounded, clast-supported limestone gravel (Mz=6.5cm), in a matrix of very dark, grayish brown (10YR3/2), organic rich (11.9%), friable granular, very poorly sorted, sandy, silty clay. Individual clasts are somewhat friable and etched by solution pitting.
II	45-115	Subrounded to subangular clast-supported limestone gravel (Mz=5.15cm) in a matrix of yellowish brown (10YR5/4), soft, plastic when moist, very poorly sorted, sandy, silty clay. Occasional small yet coherent charcoal lenses are present. Laterally and vertically, Unit II is very heterogeneous. Large roof-fall blocks occur throughout the unit and toward the rear of the cave are matrix free.
III		
a	5-10	Yellowish brown (10YR5/5), massive sandy silt, exhibiting a fine angular blocky structure when dry. The unit dips strongly toward the cave entrance in the area beneath the cave brow.
b	2-5	Laterally variable, iron-oxide gravel lens that grades towards the cave interior into a reddish-brown (5YR5/4) sandy silt and a thin clay lens.
c	1-8	Very pale brown (10YR7/3) laminated sandy silty-clay.
d	5-12	Very pale brown (10YR7/3) sandy silt.
e	4-9	Chert and iron-oxide pebble gravel in a matrix of reddish-brown (5YR5/5) silty sand.
f	12-16	Reddish brown (5YR5/5) silty sand with iron-oxide and chert pebbles.
g	3-7	Pink (7.5YR7/4) sandy silt with occasional iron oxide pebbles and granules.
h	6-12	Reddish brown (5YR4/3) silty sand with frequent iron oxide and polished chert pebbles.
i	6-44	Light yellowish brown (10YR6/4) massive sandy silt with iron oxide and chert granules.
j	27-33	Very pale brown (10YR7/3) clayey silt with abundant polished subangular to rounded chert pebbles.

Table 6. False Cougar Cave Radiocarbon Dates

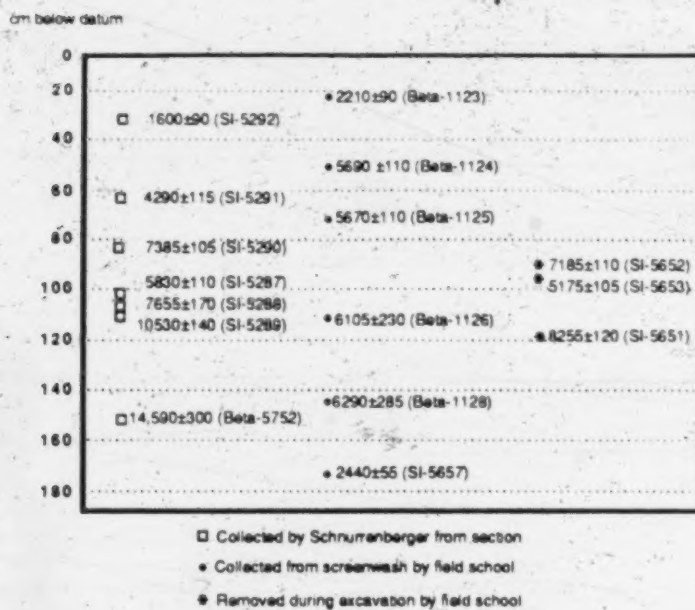


Table 7
Cave Ann
Lithostratigraphic Unit Descriptions

Unit	Thickness	Description
I	13-33cm	Dark grayish brown (10YR 3/2) sandy silty clay with occasional subangular to subrounded limestone clasts. Frequent large (greater than 10cm in length) limestone cobbles are distributed throughout this unit. Dung comprises a significant portion of this sediment.
II	35-48cm	Dark Brown (10YR 3/3) sandy silty clay with occasional subangular to subrounded limestone clasts. Small tabular (5-10cm long) and bowl-shaped accumulations of charcoal occur within this unit. Organic matter is more finely comminuted and intact specimens of dung were rare.
III	0-28cm	Light yellowish brown (10YR 6/4) sandy silt with abundant, small calcite concretions.
IV	13-22cm	Yellowish brown (10YR 5/4) sandy silty clay with frequent gravel sized clasts as well as numerous boulders greater than 10cm in length.
V	0-31cm	Very pale brown (10YR 7/3) carbonate fine sand to silt.

Table 8

Big Lip Rockshelter

Lithostratigraphic Unit Description

Unit	Unit Thickness	Description
I	25-123cm	Clast-supported angular to subrounded limestone gravels. Platy clasts are uniformly oriented parallel or subparallel to the slope of the modern surface of the shelter. Matrix consists of very poorly-sorted, sandy, silty clay. Ph values for both units were 7.4. Two sub-units recognized on the basis of matrix color and gravel percentage.
Ia	15-50cm	Subangular to subrounded, clast-supported, limestone gravel (Mz=5.65cm), with a dark brown (10YR3/2) organic, sandy silty clay matrix.
Ib	18-70cm	Subangular to angular and subrounded, clast-supported, limestone gravel (Mz=6.55cm), with a black (10YR2/1), organic, sandy silty clay matrix. Abundant charcoal flecks occur in the unit that occasionally occur as discrete chunks.
Ic	8-12cm	Subangular to subrounded limestone gravel in matrix of dark brown (7.5YR4/2) sandy silty clay matrix. This unit is not laterally extensive and in section appears bowl-shaped with an erosional lower contact.
IIa	80-93cm	Light reddish brown (5YR6/4) silty sand matrix supporting limestone and rare dolomite pebbles and granules.
IIb	30-35cm	Rounded to subrounded carbonate gravel with matrix of pink (5YR7/3) very poorly-sorted sandy silt.
IIc	22-35cm	Reddish brown (5YR4/4) very poorly sorted sandy silty clay.
IId	18-25cm	Rounded to subrounded carbonate gravel with matrix of yellowish red (5YR5/6) silty sand.
IIe	32-47cm	Yellowish red (5YR5/6) silty sand supporting carbonate pebbles and granules.
IIf	18-24cm	Rounded to subrounded carbonate gravel with matrix of pink (7.5YR7/4) sandy silty clay.
IIg	8-15cm	Reddish yellow (5YR6/6) clayey silt supporting subrounded to rounded carbonate pebbles and granules.
IIh	108-115cm	Rounded to subrounded carbonate gravel with matrix of reddish yellow (5YR6/6) silty sand.

Table 9
Crystalsin Cave
Lithostratigraphic Unit Descriptions

Unit	Unit Thickness	Description
I	40-95cm	Angular to subangular limestone gravel (Mz 4.2cm) in a matrix of brown 10YR4/3 sandy, silty, clay with a loose, friable structure. Along the south wall of the east-west trench, Unit I exhibits a series of alternating coarse fine-textured units that were at first believed to be laterally-extensive. However, subsequent excavation revealed that these were simply laterally restricted lenses richer in limestone clasts than adjacent areas. Towards mouth of the cave and on the north wall, Unit I is a thick, homogeneous unit lacking visible charcoal rich zones. The dip of Unit I is relatively small, with a slight dip towards the west (mouth of the cave) and a slightly steeper dip towards the south.
II	120-120cm	Pale yellow 2.5YR7/4, fine silt with frequent limestone clasts and fine calcite crystal fragments. Abrupt boundary to overlying Unit I in western portion of site. Clear boundary marked by thin gravel lens towards eastern part of site.
III	20-110cm	Jumbled mass of large breccia cobbles, slabs of ceiling rock and large calcite crystal formations. Unit is the uppermost unit to exhibit a strong dip to the south and west of the site.
IV	10-150cm	Pale yellow 2.5YR7/4, fine silt with rare breccia fragments.
V	60cm-?	Large tabular imbricated limestone slabs dipping to the south and west.

Table 10

Lithostratigraphic Unit Descriptions for Beyond Level Rockshelter

Unit	Thickness	Description
I	11-15cm	Brown (10YR4/3) poorly-sorted, silty sand with abundant rounded gravel-sized sandstone clasts and organic matter. The organic matter resembles a rodent midden accumulation, consisting of scats, leaves, twigs and cactus needles. Cultural materials in the form of flaked stone and paleontological remains were also located.
II	2-15cm	Brown (10YR5/4) poorly-sorted, silty sand with only small quantities (7.9%) of gravel-sized rounded sandstone fragments. There was a marked decrease in the quantity of organic matter within this unit compared with the overlying Unit I. The boundary to Unit I, marked primarily by differences in organic matter content was clear and smooth. Abundant rounded, mottled areas, interpreted as infilled rodent burrows were contained within the unit.
III	8-11cm	Dark grayish brown (10YR4/2) poorly-sorted silty sand with frequent (14.1%) gravel-sized sandstone fragments and abundant charcoal flecks and chunks. Boundary to lower unit IV was distinct and smooth.
IV	22-43cm	Pale brown (10YR6/3) poorly-sorted silty sand with abundant (35.1%) gravel-sized rounded sandstone clasts. A concave, lens of charcoal flecks was located within this unit surrounded by rounded sandstone fragments.
V	133-144cm	Light yellowish brown (10YR6/4) poorly-sorted silty sand with rare (1.3-6%) gravel-sized rounded sandstone fragments.
VI	31-39cm	Light yellowish brown (10YR6/4)-(2.5Y6/4) poorly-sorted silty sand to sand with frequent (11.9-12.5%) gravel-sized rounded sandstone fragments. This unit rests upon the weathered bedrock surface.

Table 11

Mean Monthly Temperatures (°C) for Land Regions in the Study Area

Land Region	J	F	M	A	M	J	J	A	S	O	N	D	Yr.
Mixed Grassland	-9	-5	-3	5	11	15	19	17	12	8	-1	-5	5
Fescue Grassland	-10	-7	-4	3	8	12	15	14	10	5	-2	-6	3
Parkland	-10	-7	-5	-1	7	10	14	12	9	4	-3	-7	2
Montane	-8	-6	-3	2	7	11	15	14	9	5	-2	-6	3
Subalpine	-11	-9	-6	1	6	9	13	12	7	3	-3	-8	1
Alpine	-15	-15	-13	-6	2	6	10	6	5	-4	-11	-13	-4

(Taken from Alberta Energy and Natural Resources Report No. 94, 1979).

Selected Climatic Parameters

	Mixed Grassland	Fescue Grassland	Parkland	Montane	Subalpine	Alpine
Mean number of days with temperatures <0° C(May-Sept)	10	25	40	30	50	ca. 55
Mean length of freeze free period	115	75	40	70	70	<25
Mean yearly total precipitation (mm of water equivalent)	450	500	590	530	770	590
Mean October-April total precipitation	170	220	270	230	460	330
Mean May-Sept total precipitation	280	280	320	300	310	260

(Taken from Alberta Energy and Natural Resources Report No. 94, 1979).

Table 12

Lithostratigraphy of Cave 1

Unit	Thickness	Description
I	2-45cm	Brown (10YR4/3), organic rich (17.7%) very poorly sorted, clayey silt to sandy, silty, clay with abundant predominantly subangular to sub-rounded limestone gravel (57.9%; Mz=4.35).
II	5-25cm	Brown (10YR5/3), very poorly sorted, clayey silt, with abundant predominantly angular to sub-angular limestone gravel (41.6-54.1%; Mz=4.45-4.9).
III	75-110cm	Olive brown (2.5Y4/4) to light Olive brown (2.5Y5.4) poorly sorted silt to clayey silt with rare included limestone clasts.

Table 13

Lithostratigraphy of Cave II

Unit	Thickness	Description
I	0-15cm	Very dusky red (10R2.5/2) organic rich (55.8%) sandy, silty, clay with abundant (68.7%) angular to subangular limestone gravels (Mz=4.7cm).
II	70cm	Dark red brown (5YR2.5/2) to dark reddish brown (5YR3/2), organic rich (54.6-20%) poorly to extremely poorly sorted, silty sand to sandy, silty, clay with abundant (67.7-54.3%) angular to subangular limestone gravels (Mz=4.0-4.7cm).
III	22-32cm	Olive (5Y4/3), poorly sorted silt with occasional subangular to subrounded limestone gravels.

Table 14

Lithostratigraphy of Cave III

Unit	Thickness	Description
I	20-30cm	Dark red brown (5YR2.5/2) to very dusky red (10YR2.5/2), very poorly sorted, sandy, silty, clay with abundant angular to subangular limestone gravels (41.6-57.7%).
II	15-33cm	Dark red brown (5YR3/2), very poorly sorted, sandy, silty, clay with abundant subangular to subrounded limestone gravels (31.2-79.3%; Mz=4.8cm)
III	15-35cm	Dark grayish brown (2.5Y4/2), very poorly sorted, sandy silt with frequent subangular to subrounded limestone gravels (14.6%).

Table 15
† Climatic Data for Sites

Site	Mean Annual Temperature (°C)	Mean January Temperature (°C)	Annual Frost- Free Days (°C)	Mean Annual Precipitation (mm)
Yukon Caves	-14	-15	70	215
January Cave	-4	-15	25	590
Racehorse Creek Rockshelter	1	-11	70	770
Cave Ann False Cougar Cave	4.5	-4	45	370
Crystalsin Cave Big Lip Rockshelter	6	1	65	175

†Data in this table were derived by taking the nearest weather station for which data were available and extrapolating either up or down in elevation using an temperature gradient of 6.4 °C/1000 m. Temperature and moisture data were extracted from the following sources; Pryor Mountains: Sage Creek Station (South 1980); Southern Alberta: Alberta Energy and Natural Resources (1979); Yukon: Old Crow (Lauriol et al. 1988).

Table 16
Measures of Dispersion for the A fraction Percentage

Site	Mean	Standard Deviation	Variance	Coefficient of Variation (CV)
Cave I	48.74	6.98	3.12	14.33
Cave II	63.61	6.48	42.00	10.19
Cave III	62.74	11.24	126.43	17.92
January Cave	13.28	7.47	55.85	56.29
Racehorse Creek Rockshelter	40.84	13.48	181.78	33.01
Cave Ann	10.92	10.01	100.09	91.62
False Cougar Cave	43.02	12.40	153.83	28.83
Crystalsin Cave	46.31	22.25	495.11	48.05
Big Lip Rockshelter	70.07	10.68	114.02	15.24
All Sites Combined	54.99	20.30	413.1	44.20

Table 17
Measures of Dispersion for the Mean Size of A fraction Clasts

Site	Mean	Standard Deviation	Variance	Coefficient of Variation (CV)
Cave I	4.48	0.24	0.06	5.39
Cave II	4.44	0.23	0.05	5.24
Cave III	4.53	0.51	0.26	11.35
January Cave	4.03	0.79	0.62	19.49
Racehorse Creek Rockshelter	3.43	0.48	0.23	14.10
False Cougar Cave	5.37	0.77	0.59	14.35
Crystalsin Cave	4.13	0.96	0.92	23.24
Big Lip Rockshelter	6.1	0.64	0.41	10.43
All Sites Combined	4.28	0.97	0.94	22.65

Table 18

Estimated Average Sedimentation Rates for Sites Discussed in this Study

Site	Sedimentation Rate (C ¹⁴)	Sedimentation Rate (max.)
False Cougar Cave	11 cm (14,000 yrs BP)	
Crystalsin	17cm (4000 yrs BP)	
Big Lip Rockshelter	13cm (7500 yrs BP)	
Bluefish Caves		15-10cm (13,000 yrs BP)
Racehorse Creek Rockshelter	16cm (3000 yrs BP)	
January Cave	5cm (30,000 yrs BP)	15cm (10,000 yrs BP)

		Stadial Phases	Inferred Climate	Inferred Stratigraphic Span	
Late Pleistocene	Würm IV	?	temperate	LA MADELEINE GARE DE COUZE FAURELIE II FLAGEOLET II PONT D'ARCON	
		10	colder and drier		
		9	mild and humid		
		8	cold and dry		
		7	milder and humid		
		6	cold and dry		
		5	very mild and humid		
		4	cold and dry		
		III	mild and humid		
		II	cold, relatively dry		
		I	temperate, very humid		
Late Pleistocene	interstadial				
	Würm III	XIV	colder, relatively dry	LAUGENIE-HAUTE EST LAUGENIE-HAUTE OUEST LE HALPAS	
		XIII	mild and humid		
		XII	colder, relatively dry		
		XI	mild and humid		
		X	very cold and dry		
		IX	milder, more humid		
		VIII	cold and dry		
		VII	moderate and humid		
		VI	cold and dry		
		V	mild and humid		
		IV	cold and dry		
		III	mild and humid		
		II	very cold and dry		
		I	mod. cold, very humid		
	interstadial		temperate		

Figure 1. Partial master diagram for the Perigord climato-stratigraphic scheme (redrawn from Laville et al. 1980: 135). Sites are correlated to each other, and to stadial phases of the Würm glaciation of the Alpine sequence, based largely on inferred climate of deposition of cave and rockshelter sedimentary strata, and stratigraphic position.



Figure 2. Location of cave study sites investigated in this study, in Northern Yukon, southwestern Alberta, and southcentral Montana (RCRS=Racehorse Creek Rockshelter).

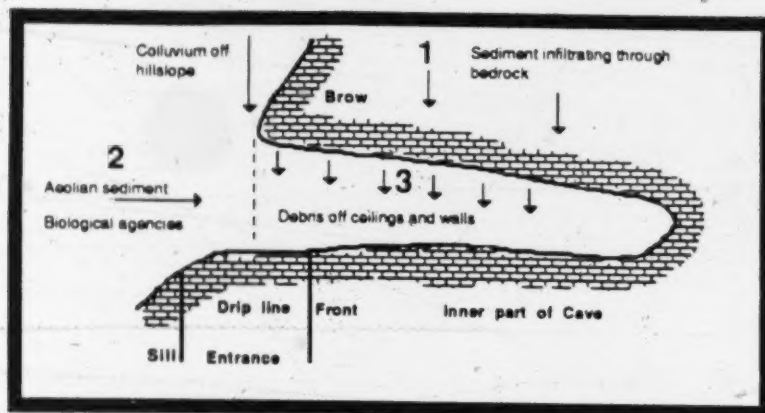


Figure 3. Sources and distribution of the various sediments in a cave (after Schmid 1969).

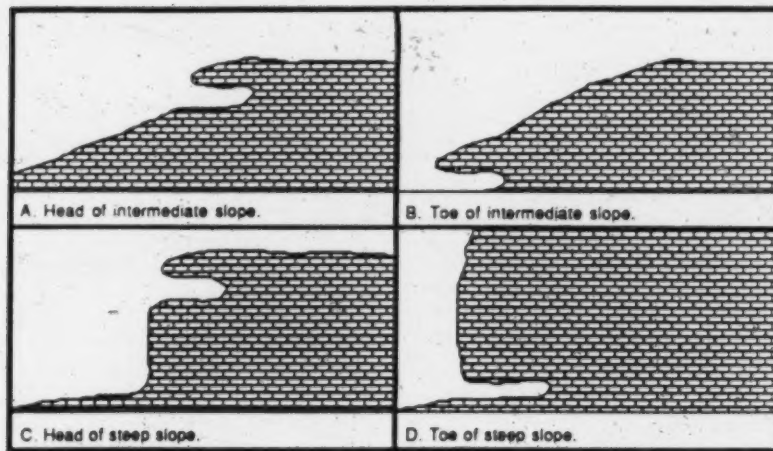


Figure 4. Location of caves and rockshelters with respect to position on slope.



Figure 5. Location map of the Pryor Mountains and adjacent mountain ranges in southern Montana and northern Wyoming.

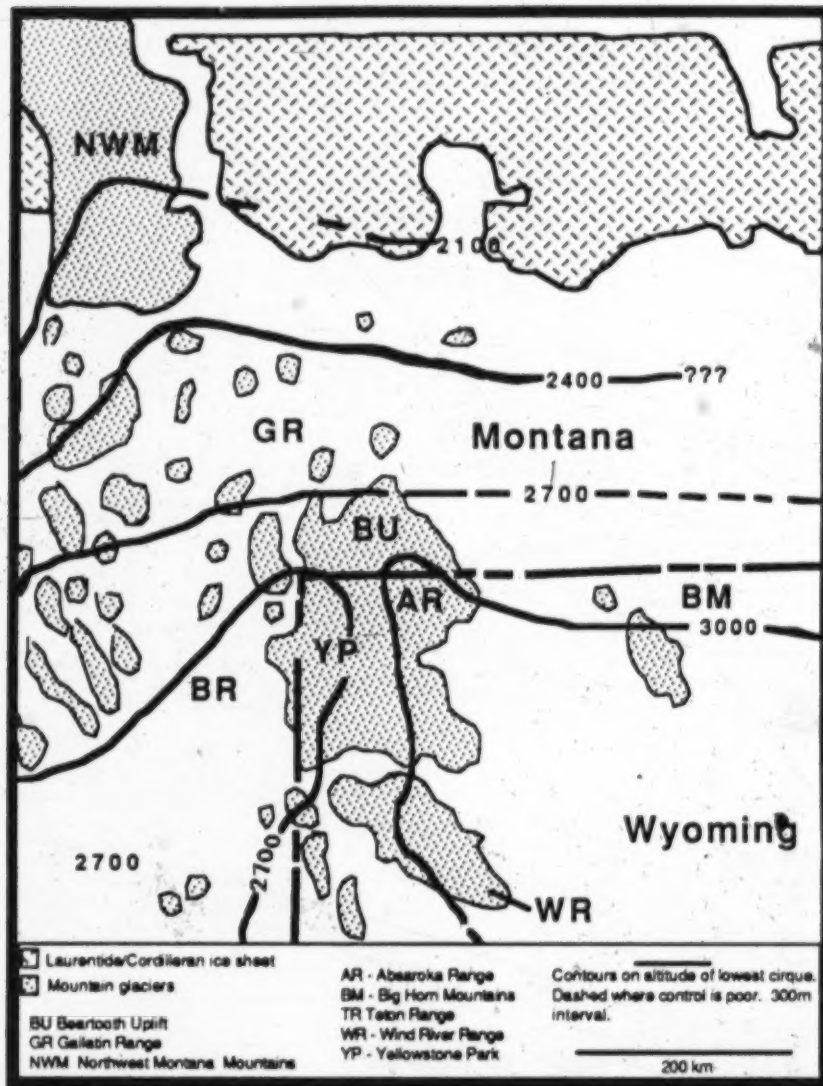


Figure 6. Distribution of mountain glacier complexes and position of Laurentide and Cordilleran ice sheets in western North America (After Porter et al. 1983).

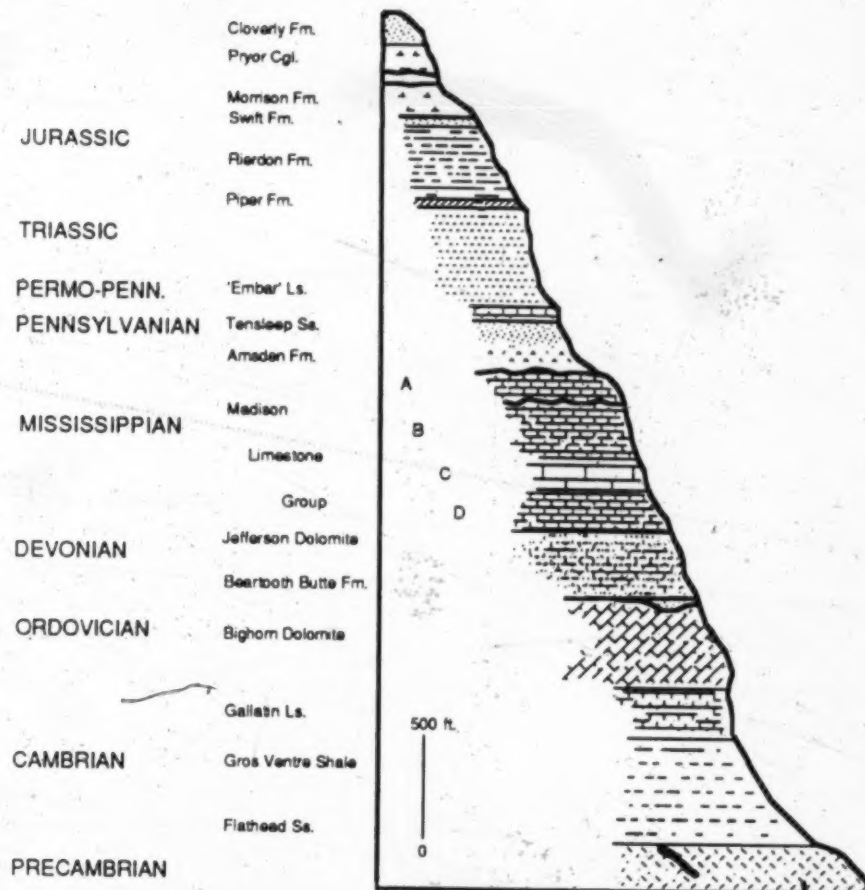


Figure 7. Lithostratigraphy of the Pryor Mountains area (after Blackstone 1975).

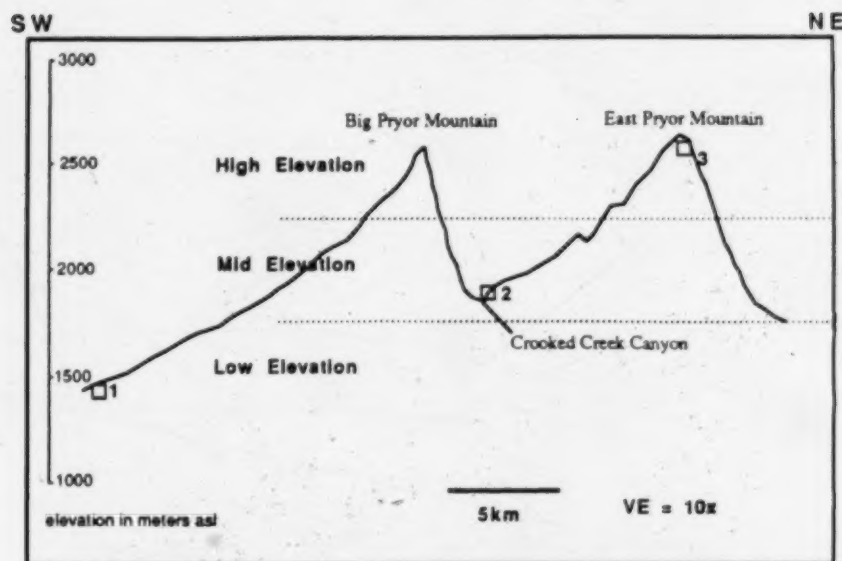


Figure 8. Schematic topographic profile from the southwestern edge of Big Pryor Mountain adjoining the Big Horn Basin to the northeastern margin of the mountains below Dryhead Overlook. 1 = Beyond Level Rockshelter and Shallow Promise. 2 = Big Lip Rockshelter and Crystalsin Cave. 3 = False Cougar Cave and Cave Ann.

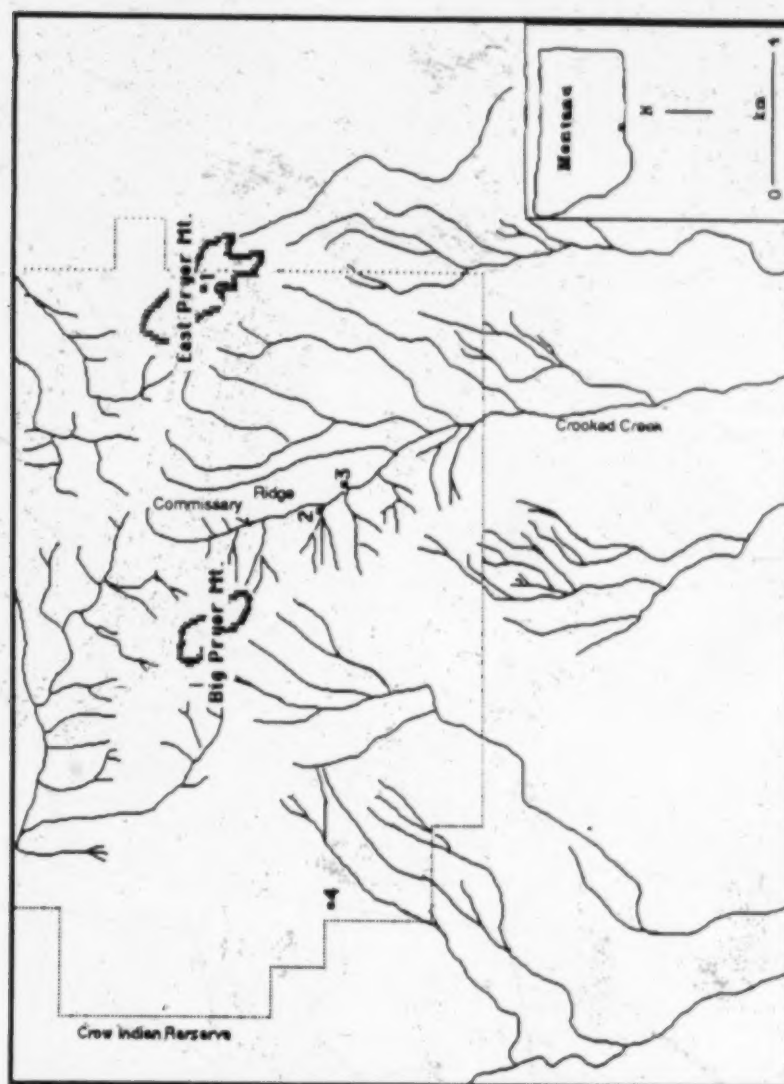


Figure 9: Location of the Pyror Mountains and study sites within the area of south central Montana.
 1=High elevations sites; 2=Crystalsin Cave, 3=Big Lip Rockshelter; 4=Low elevation sites.

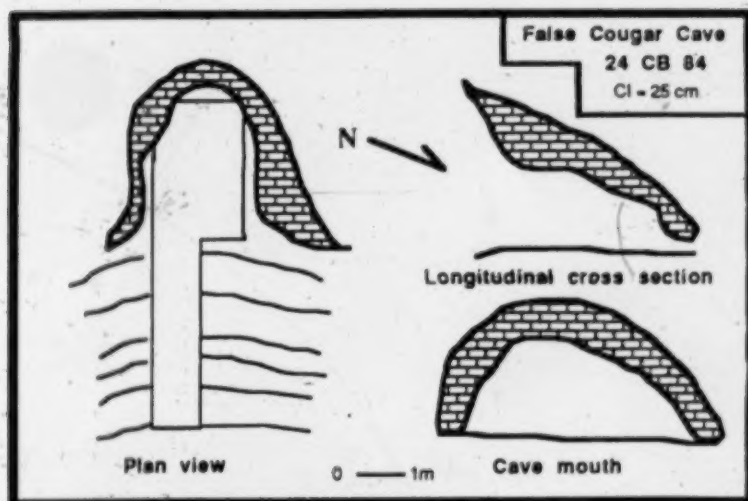


Figure 10. False Cougar Cave, plan view, longitudinal section and transverse section at cave mouth before excavation. Redrawn from Bonnichsen 1981.

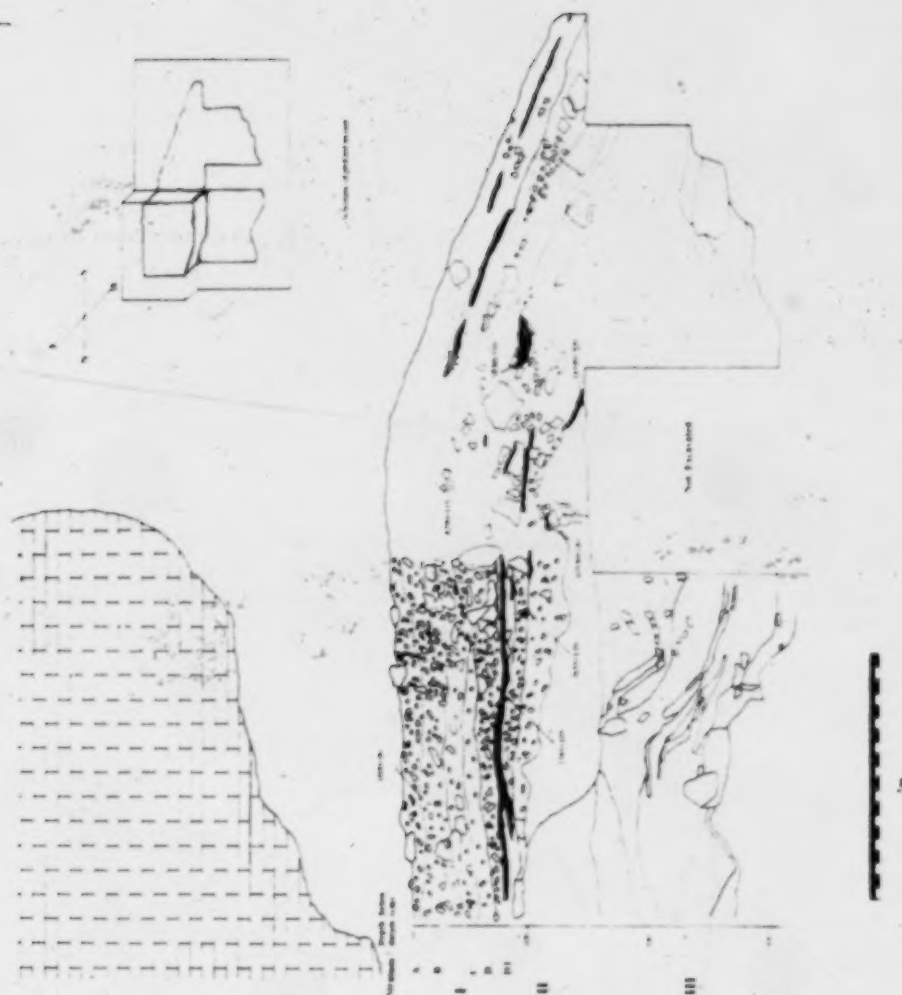


Figure 11. Section profile of False Cougar Cave. Depth with respect to site datum and lithostratigraphic unit designation are plotted to left of profile. Radiocarbon samples taken from section by Schumacher are plotted on profile. Approximate density of gravel-sized clasts are schematically represented for section inside cave. Section drawing of outside area beyond cave brow shows only larger clast.

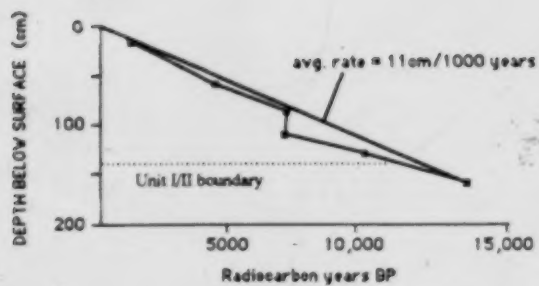


Figure 12. Curve of sedimentation rate for Units I and II at False Cougar Cave. Black squares indicate location of samples.

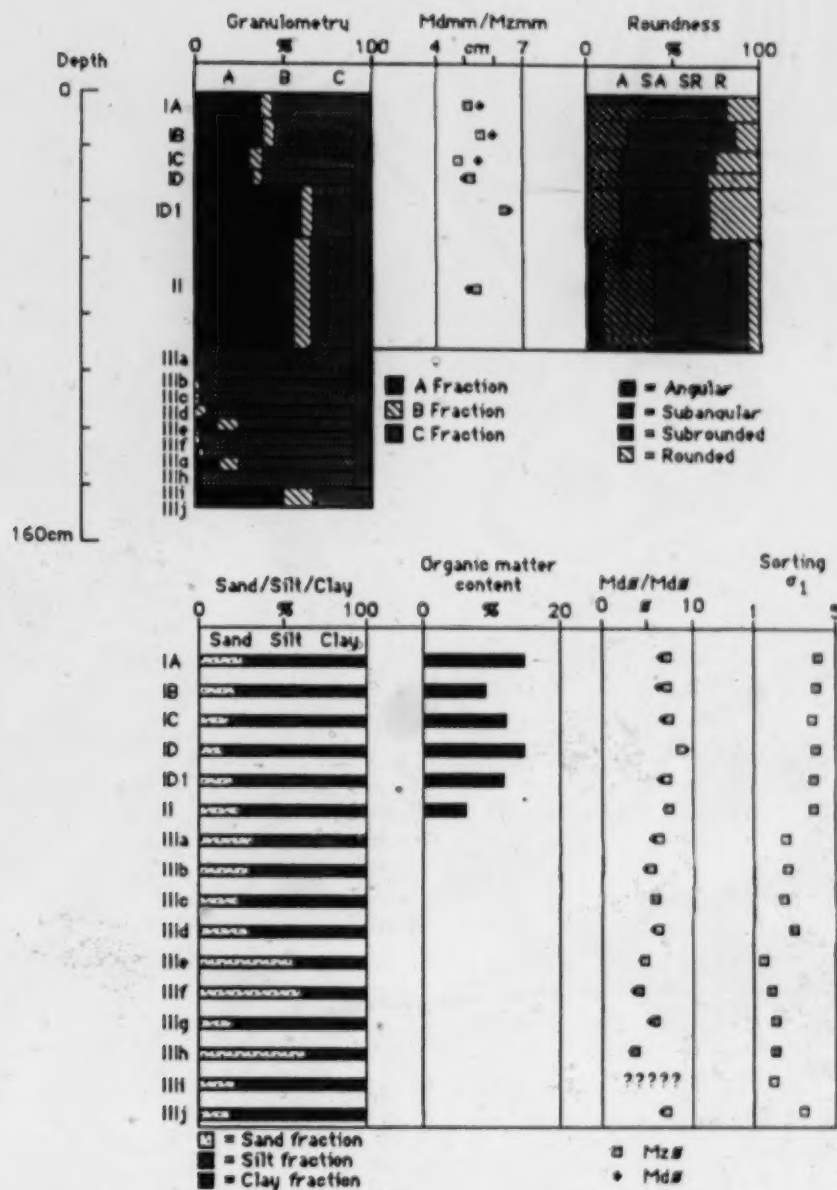


Figure 13. Sedimentological data for the A and C fractions from sediment samples at False Cougar Cave. Lithostratigraphic unit plotted on vertical axis. In upper diagram, thickness of histogram corresponds to thickness of units. Grain size and roundness of A fraction clasts were not calculated for Unit III due to small sample size. ????? = missing data.

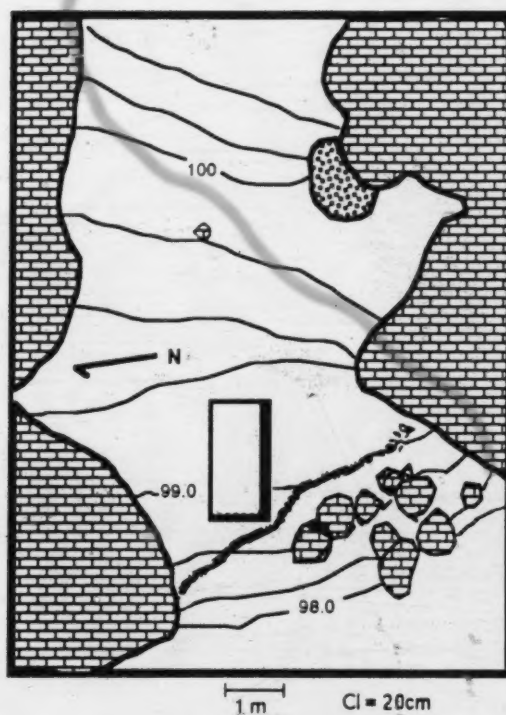


Figure 14. Planview of Cave Ann, 24 CB 163. ■ = profiled walls; ▨ = limestone bedrock; ⊖ = roof-fall blocks; ■ = dripline; ⊠ = packrat midden.

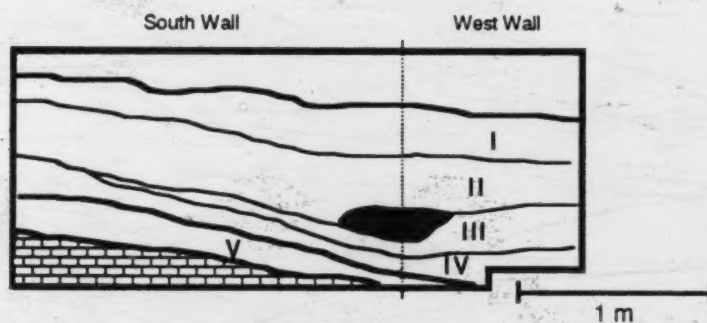


Figure 15. Cave Ann profile of excavation. Dotted line indicates corner of excavation.

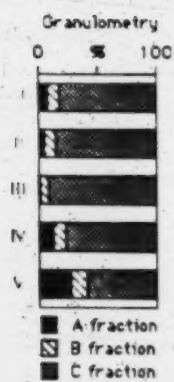


Figure 16. Histogram of granulometry of the coarse fraction of sediment samples from Cave Ann.

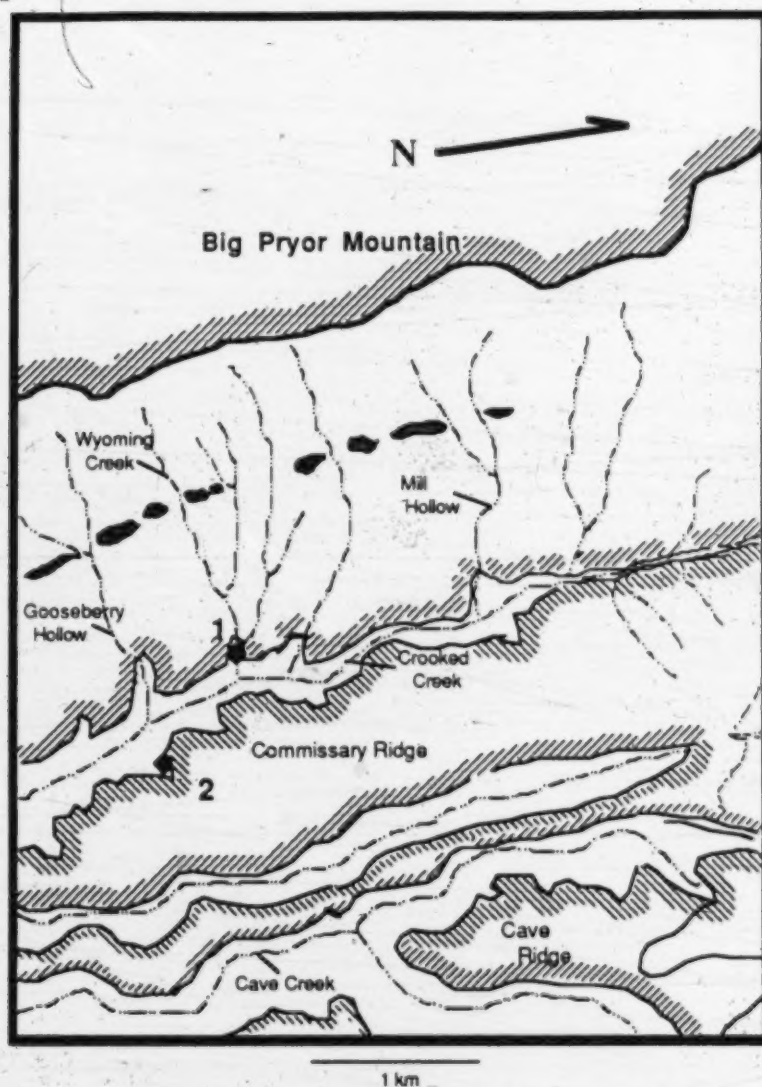


Figure 17. Location map of Big Lip Rockshelter (1) and Crystalsin Cave (2). ■ = Resistant dolomite ridge; ▨ = Escarpment edge.

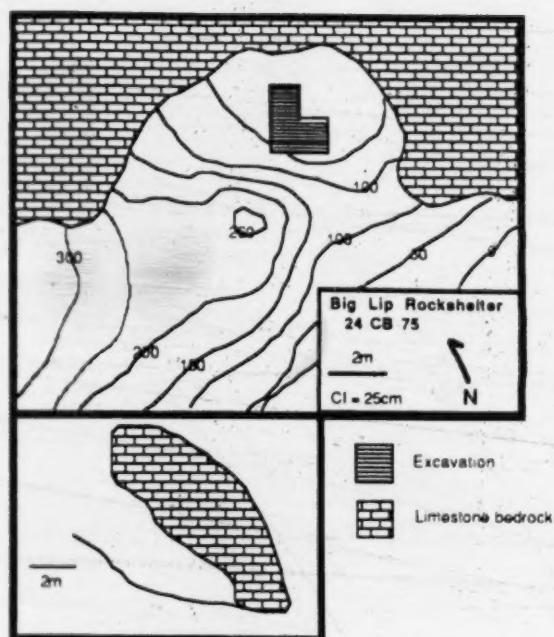


Figure 18. Big Lip Rockshelter, plan and longitudinal cross section.
Redrawn from McMahon et al. (1980).

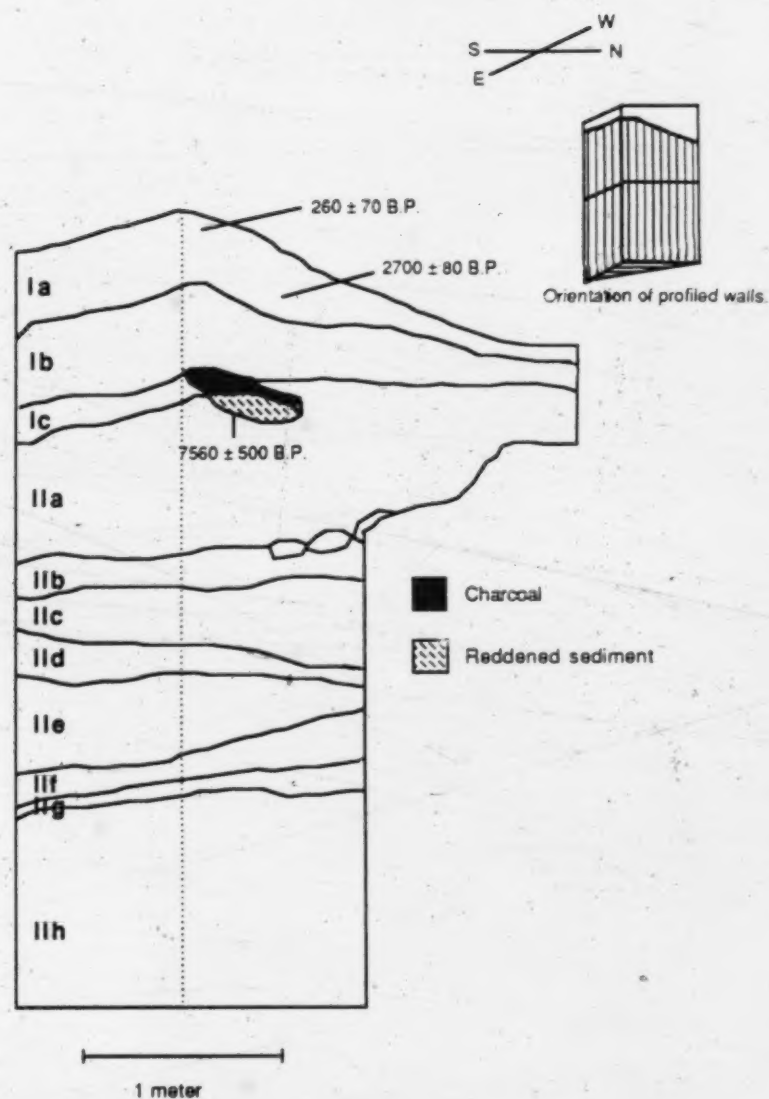


Figure 19. Big Lip Rockshelter (24 CB 75), west and south wall profile. Locations of radiocarbon dated charcoal samples plotted on profile.

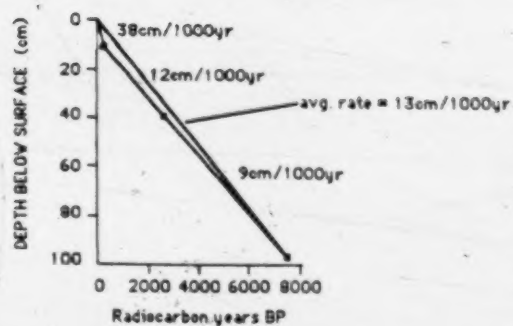


Figure 20. Curve of sedimentation rate of Units Ia, b and c at Big Lip Rockshelter. Radiocarbon dates are plotted as black squares with respect to age and depth below surface.

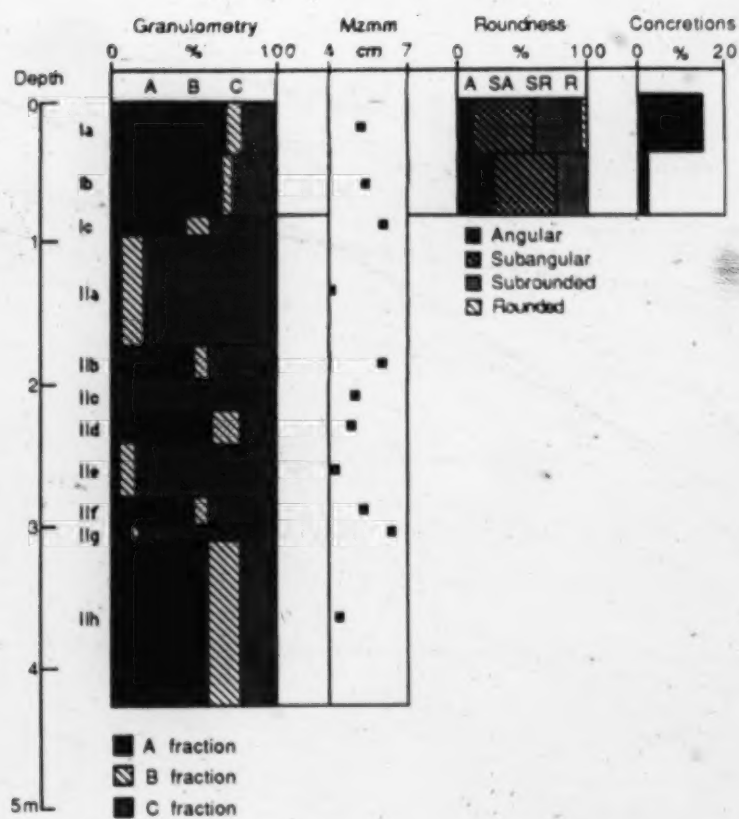


Figure 21. Sedimentological data for Big Lip Rockshelter, A fraction and global granulometry. Thickness of histogram bars corresponds to unit thickness.

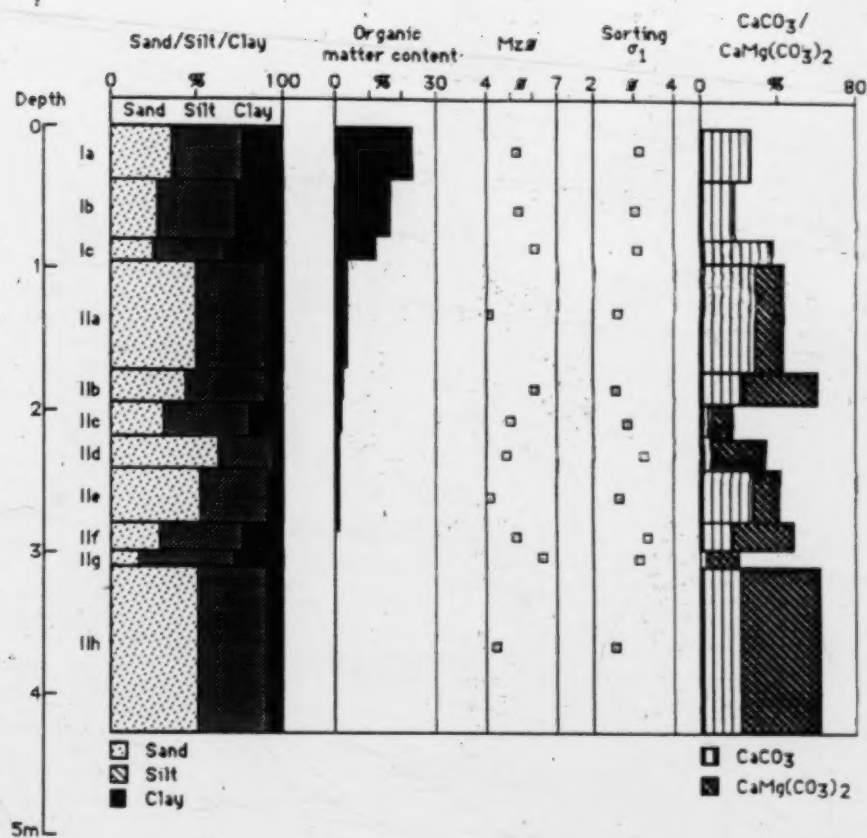


Figure 22. Sedimentological data for the C fraction of sediments from Big Lap Rockshelter. Thickness of histogram bars corresponds to thickness of lithostratigraphic units.

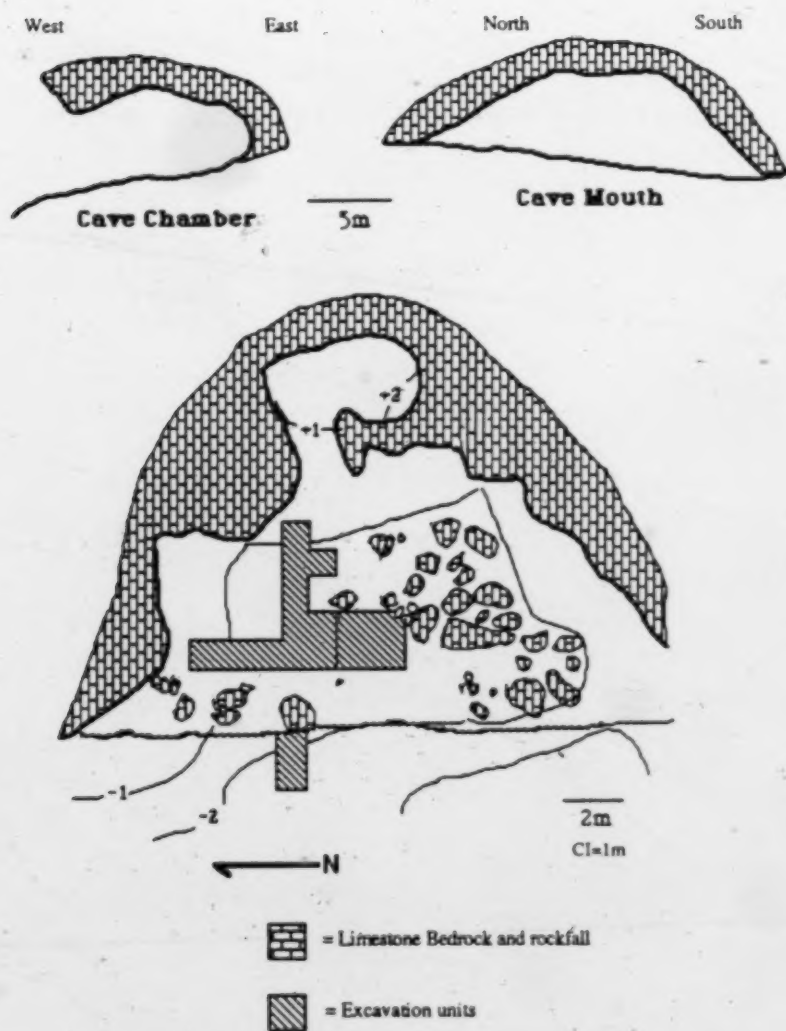


Figure 23. Planview and transverse and longitudinal cross-sections of Crystalsin Cave.

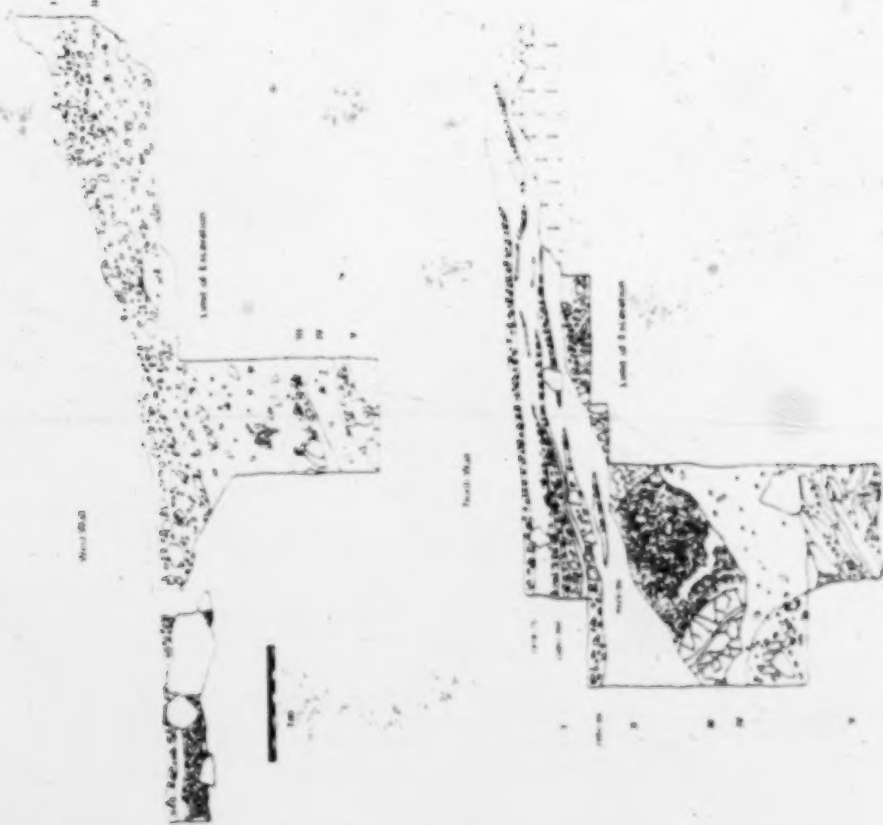


Figure 24. Crystalum Cave section profiles of north and west walls.

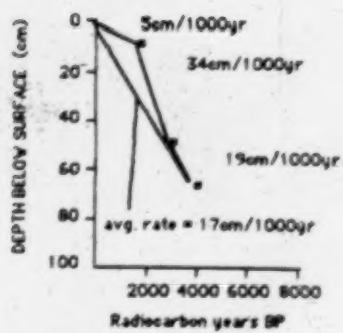


Figure 25. Curve of sedimentation rate for Units I and II at Crystal Cave.

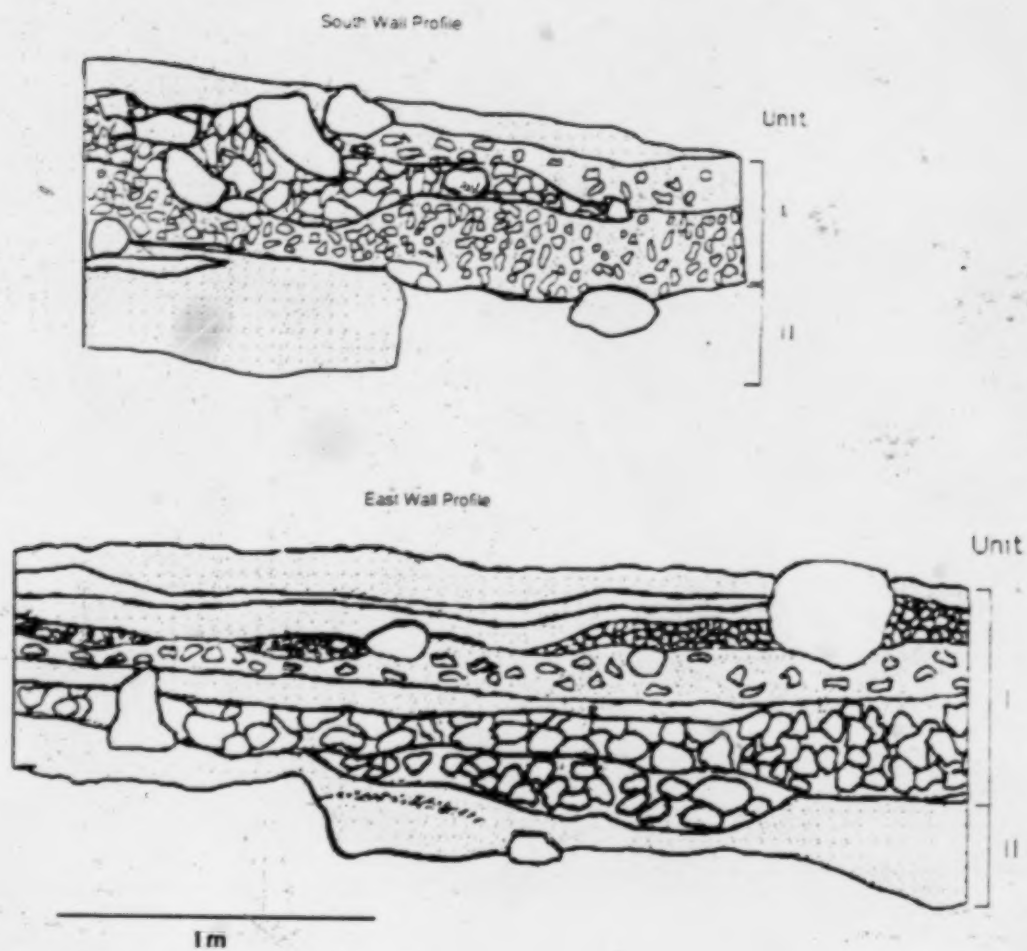


Figure 26. Section profiles of east and south walls of Crystal Cave.

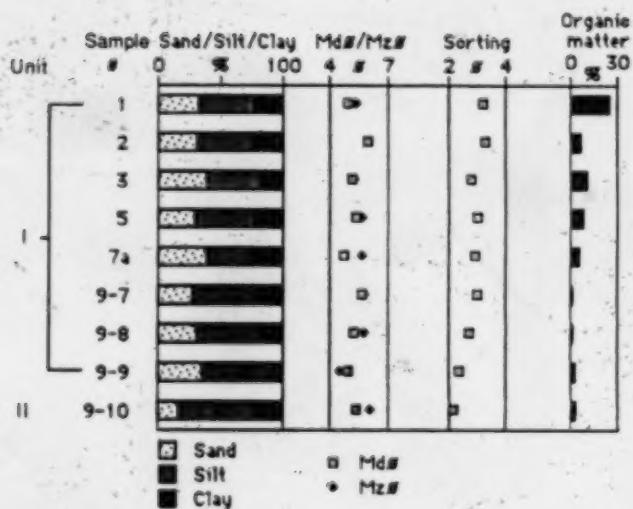
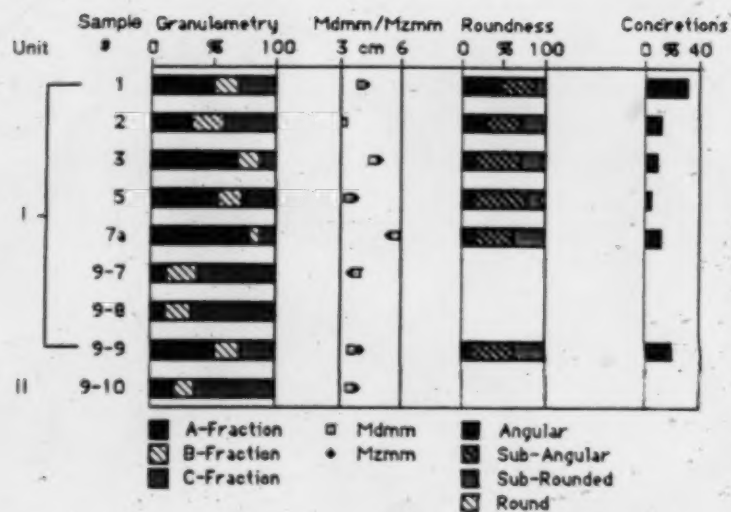


Figure 27. Sedimentological data for A and C fractions of samples from Sample Column I, Crystalsin Cave.

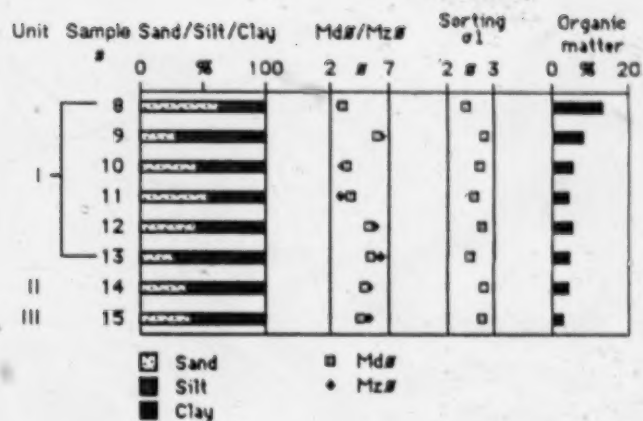
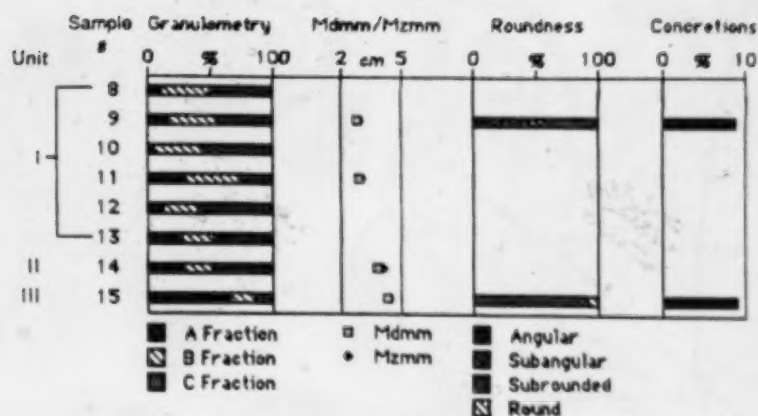


Figure 28. Sedimentological data for A and C fractions of samples from Sample Column 2, Crystalsin Cave.

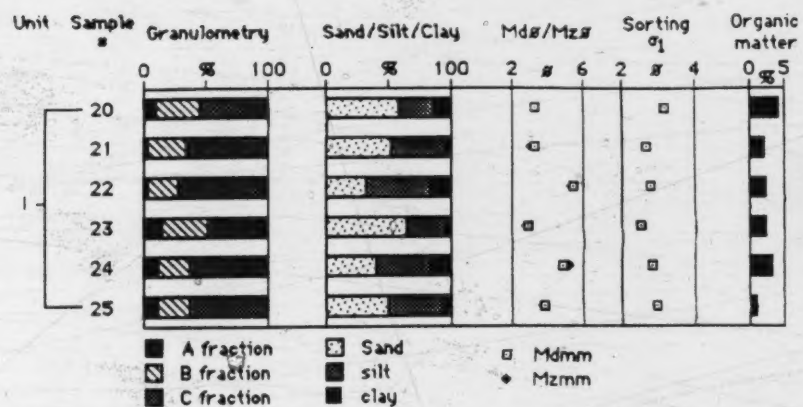


Figure 29. Sedimentological data for A and C fractions of samples from Sample Column 3, Crystalsin Cave.

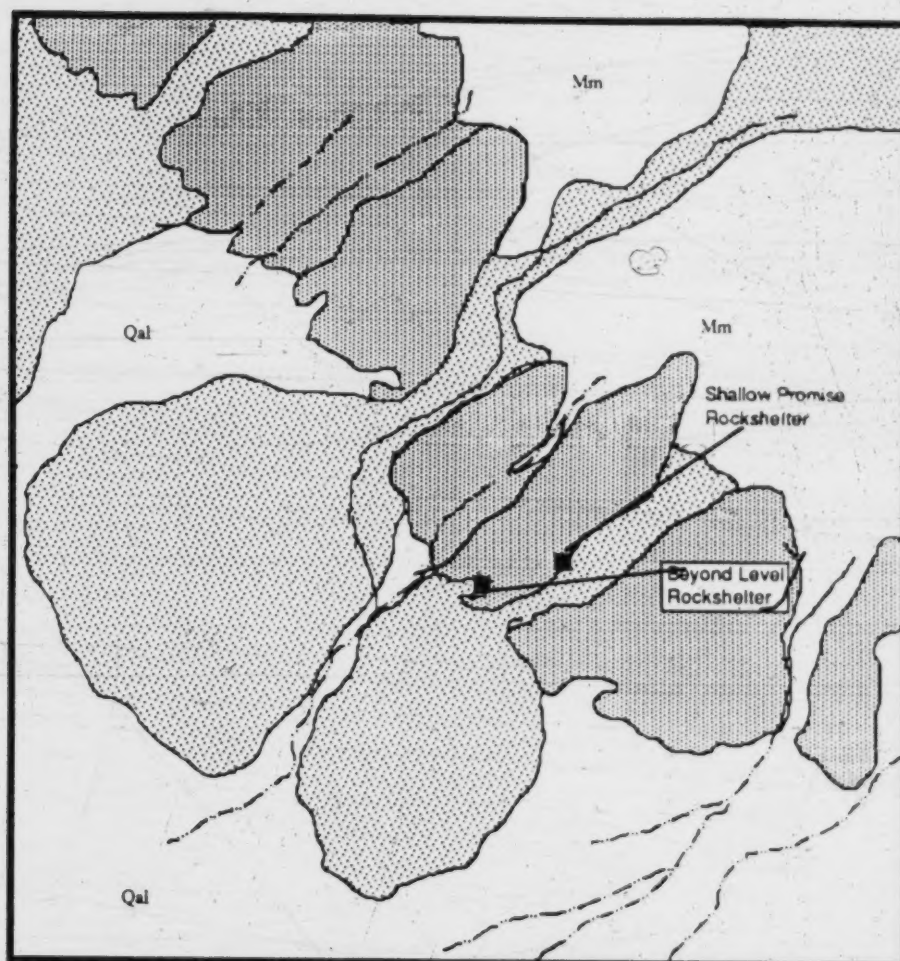


Figure 30. Location map of Shallow Promise Rockshelter and Beyond Level Rockshelter.

-  = Pennsylvanian Tensleep Sandstone
-  = Quaternary alluvial fan sediment
- Mm = Mississippian Madison Group
- Qal = undifferentiated Quaternary alluvium

Shallow Promise Rockshelter

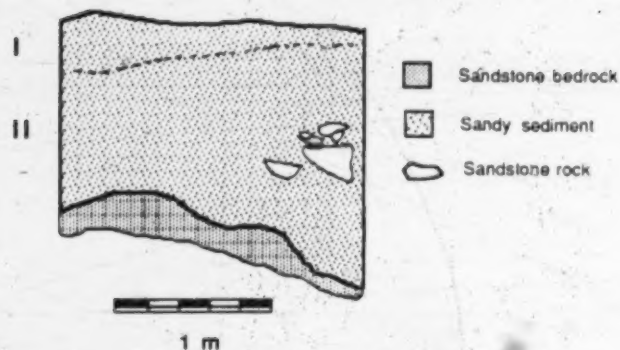


Figure 31. Shallow Promise Rockshelter stratigraphic section. Stratigraphic unit divisions are indicated by roman numerals.

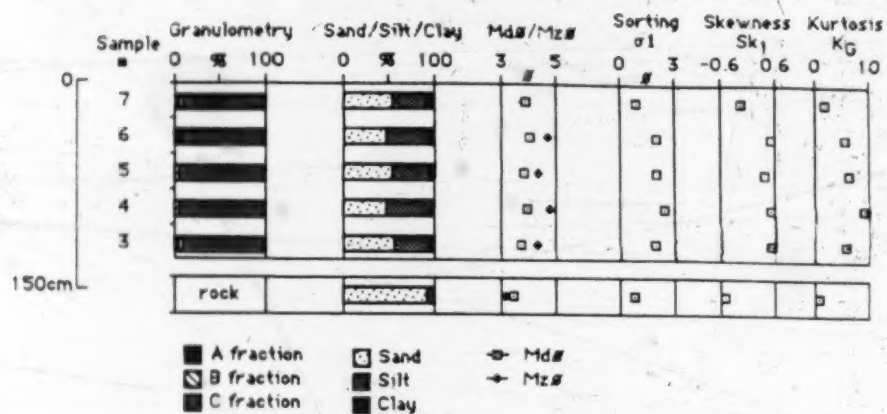


Figure 32. Sedimentological data for A and C fractions of sediments from Shallow Promise Rockshelter.

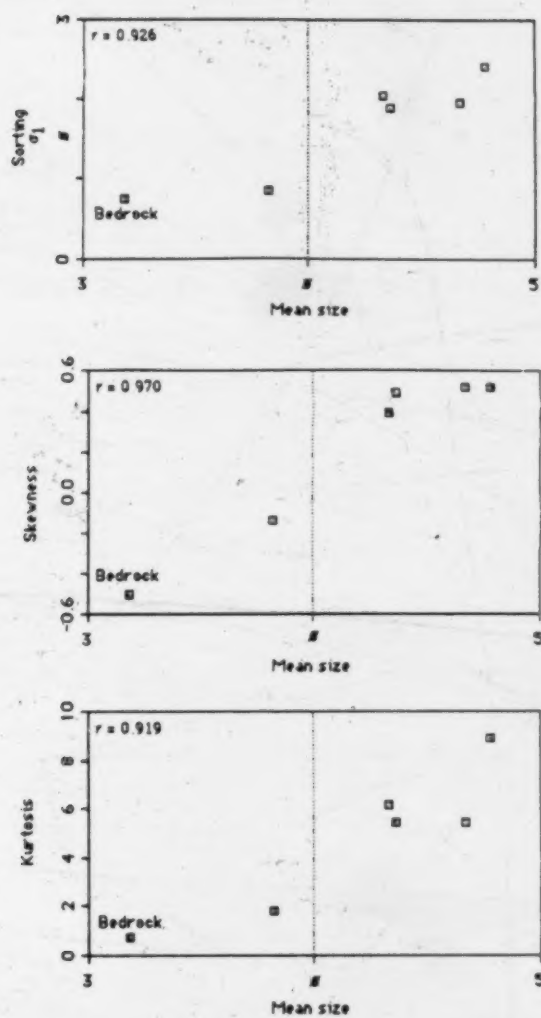


Figure 33. Scatterdiagrams illustrating variation of sorting, skewness, and kurtosis with the mean size of clasts in the fine fraction.

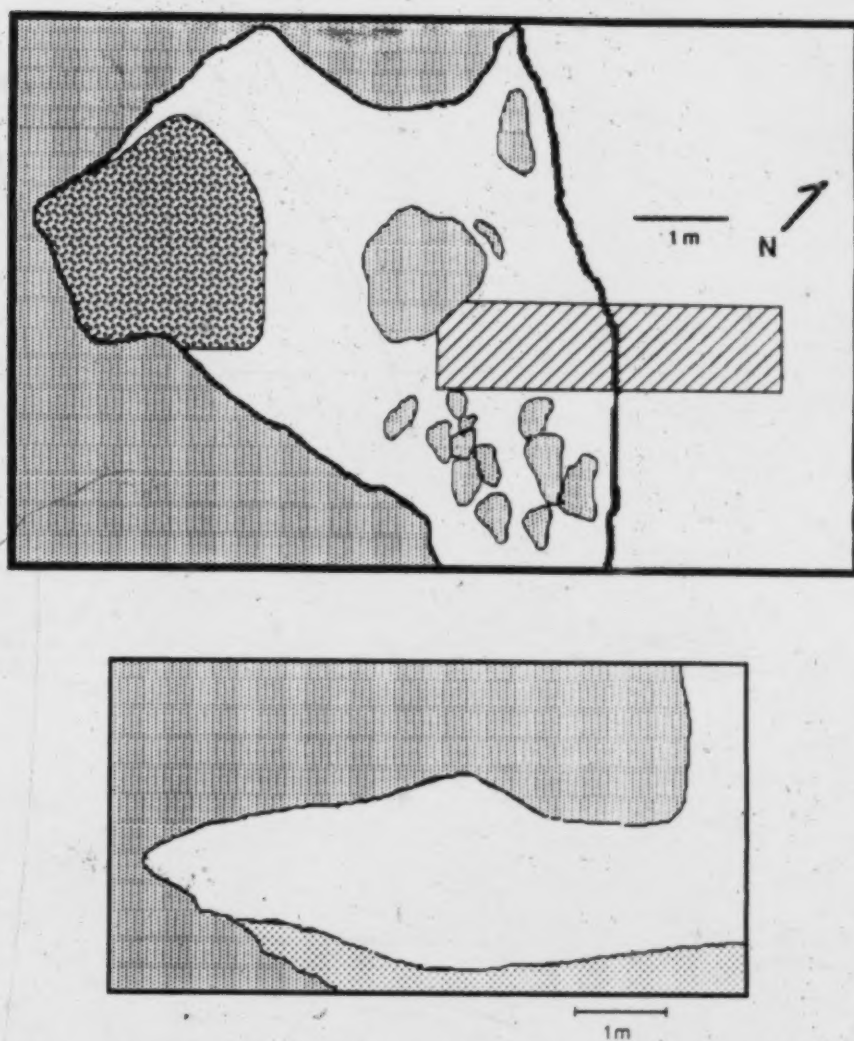


Figure 34. Beyond Level Rockshelter, planview (upper) and transverse cross-section (lower).  = sandstone bedrock or roof/fall blocks,  = cave fill,  = packrat midden,  = excavation.

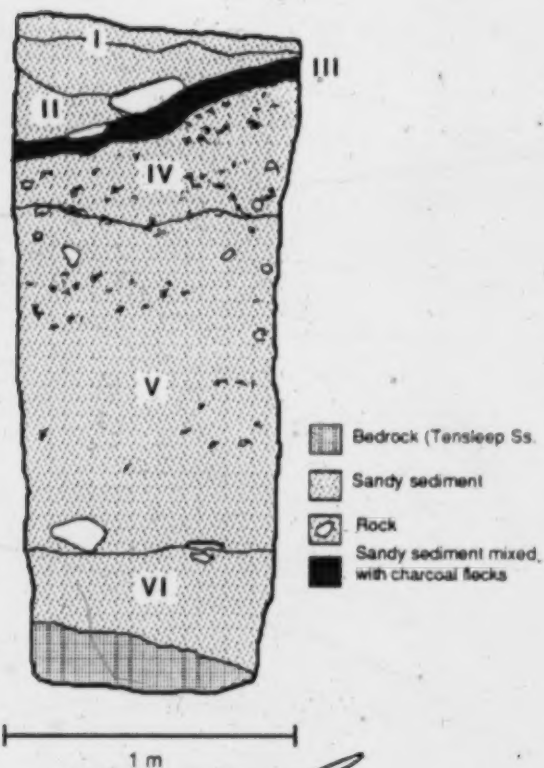


Figure 35. Beyond Level Rockshelter, south wall profile, sq. 4.2. Roman numerals refer to sedimentary units described in text.

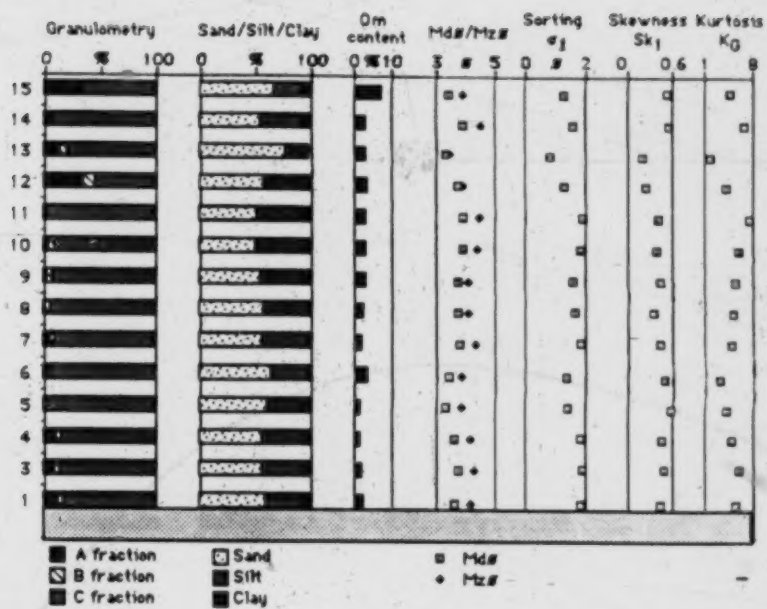


Figure 36. Sedimentological data for Beyond Level Rockshelter.

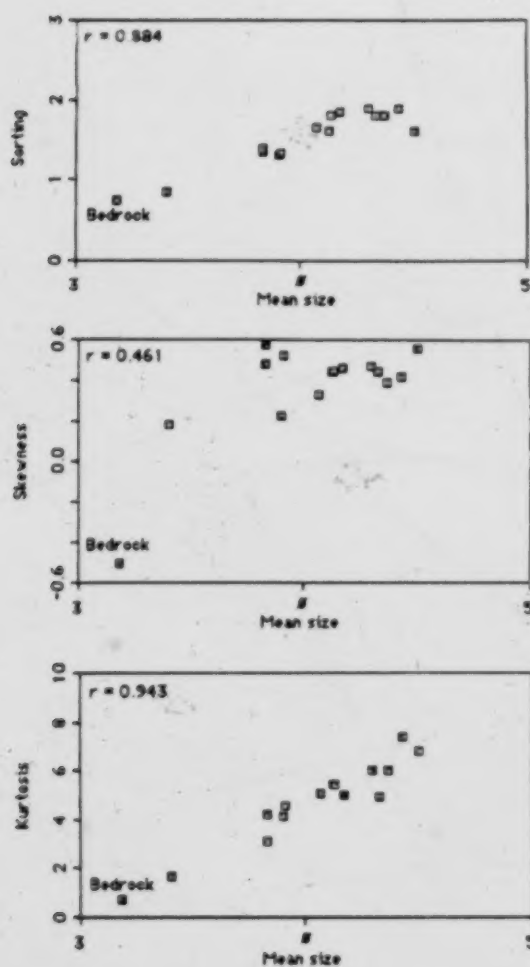


Figure 37. Scatterdiagrams of mean size versus sorting, skewness and kurtosis for sediment samples from Beyond Level Rockshelter.

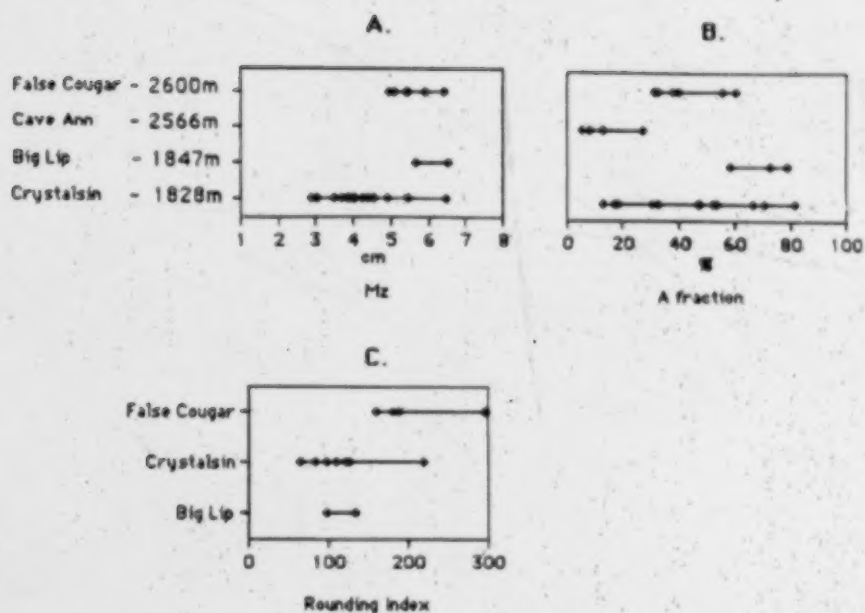
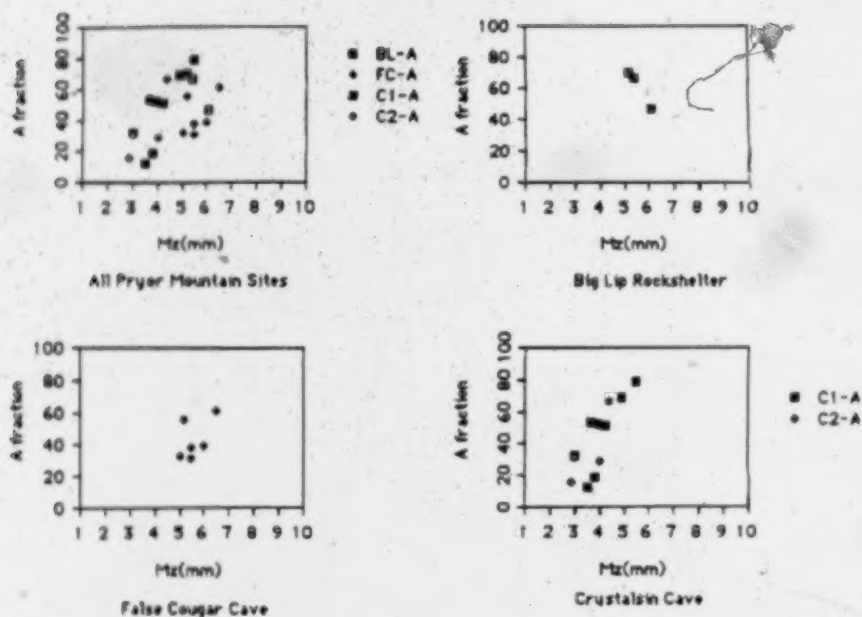


Figure 38. Comparison diagrams for upper and middle elevation sites in the Pryor Mountains; A. Range of mean size of A fraction clasts; B. Range of percentage sample composed of A fraction; C. Range of rounding as measured by the rounding index.



Site	Correlation Coefficient
False Cougar Cave	$r = 0.508$
Crystalsin Cave	$r = 0.7123$
Big Lip Rockshelter	$r = \text{not calculated}$
All Sites	$r = 0.573$

Figure 39. Scatterdiagrams illustrating variation of the mean size of A fraction clasts (x-axis) with percentage of sample composed of A fraction clasts for Pryor Mountain study sites. Table beneath scatterplot gives correlation coefficient (R).



Figure 40. Location map of January Cave and Racehorse Creek Rockshelter in southwestern Alberta.

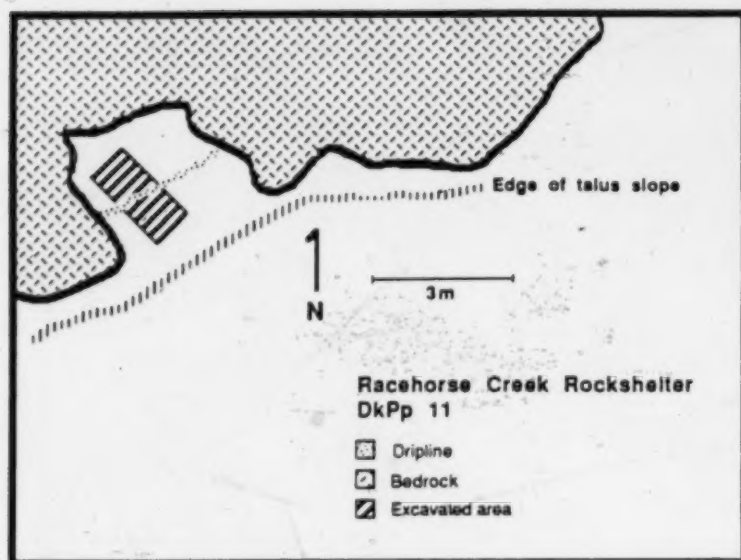


Figure 41. Planview of Racehorse Creek Rockshelter.

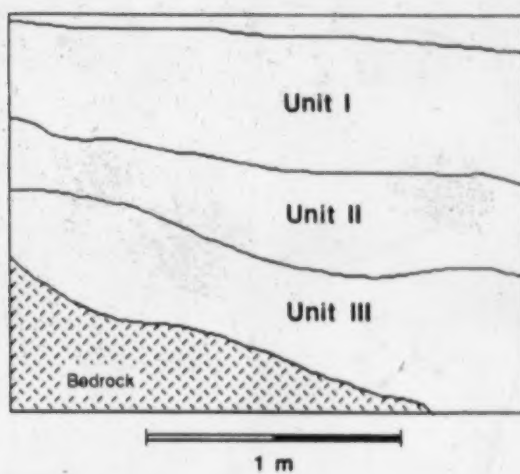


Figure 42. Schematic section profile of Racehorse Creek Rockshelter.

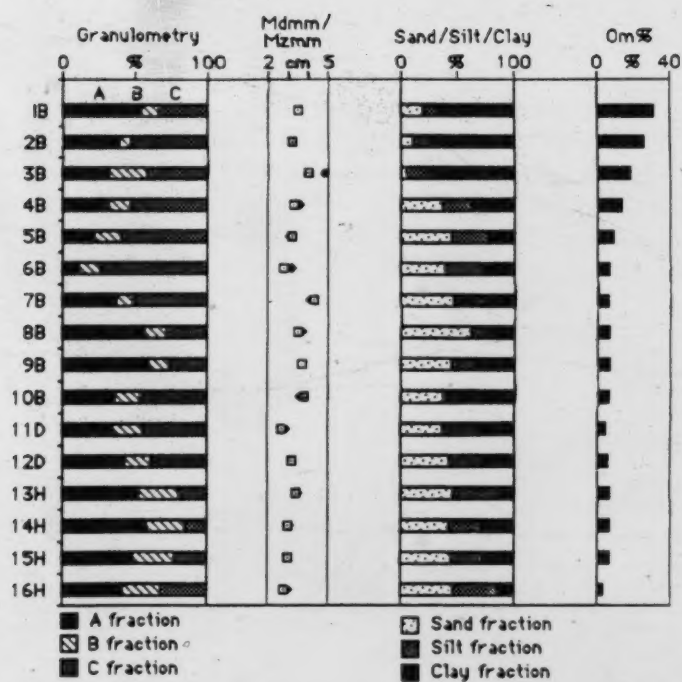


Figure 43. Sedimentological data for A and C fractions of samples from Racehorse Creek Rockshelter.

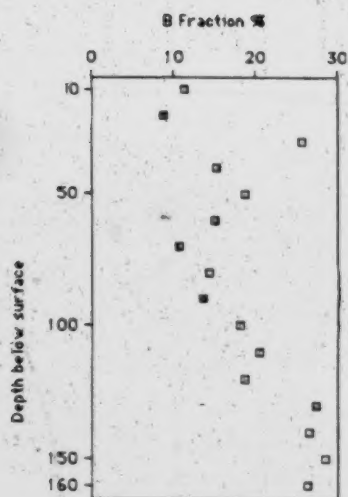


Figure 44. Variation of the medium fraction (%) with depth at Racehorse Creek Rockshelter.



1



2



3

Figure 45. Hypothetical evolution of the geomorphic position of the sediment accumulation in Racehorse Creek Rockshelter.

System		LITHOSTRATIGRAPHY	
	Series		
Permian	Upper		
			Fantasque Fm
	Lower		Ishbel Group
Pennsylvanian	Upper	Rocky Mountain Group	
	Middle		Kananaskis Fm
	Lower		Misty Fm
Mississippian	Upper	Rundle Group	Etherington Fm
			Mt. Head Fm
	Lower		* Livingston Fm
			Banff Fm
			Exshaw Fm

Figure 46. Lithostratigraphy for Plateau Mt. area (after Burns 1984). * = January Cave.

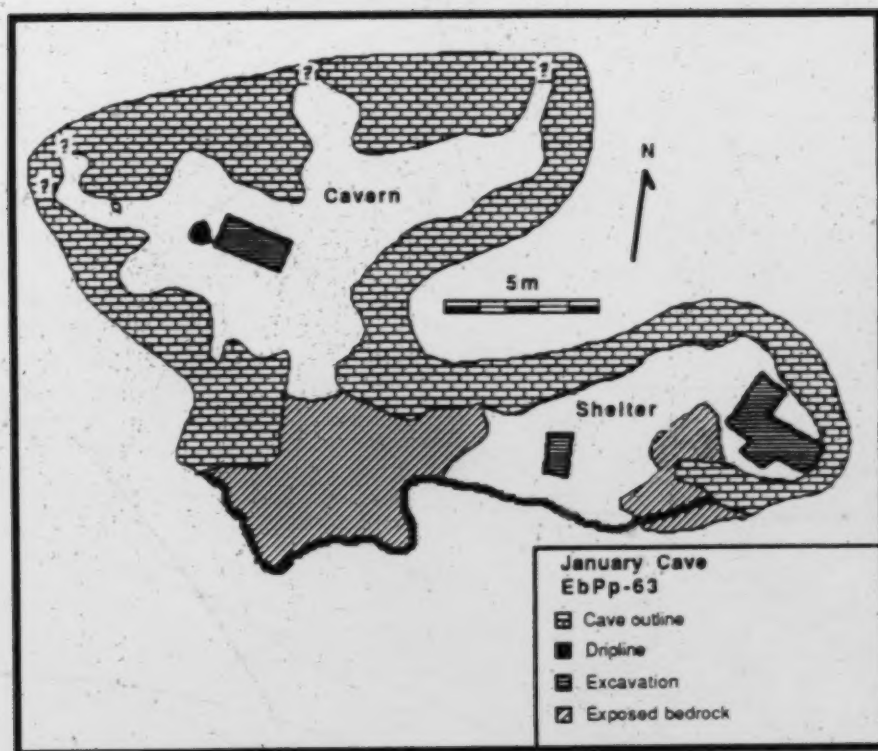


Figure 47. Planview of January Cave, redrawn from Burns (1984).

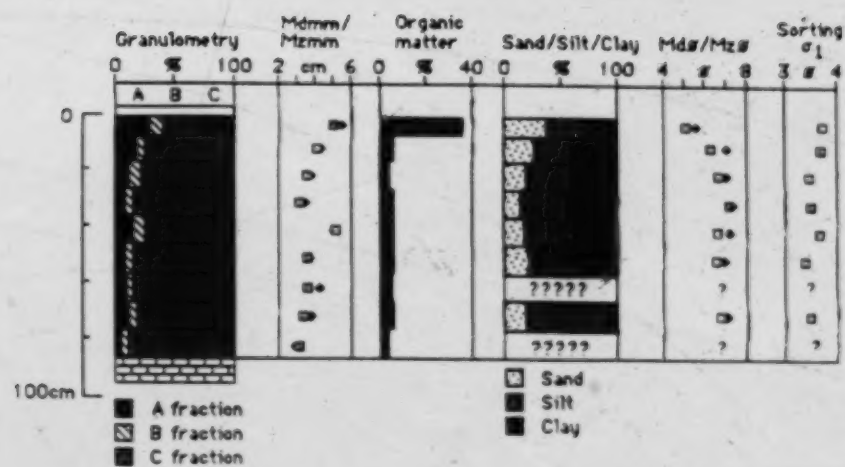
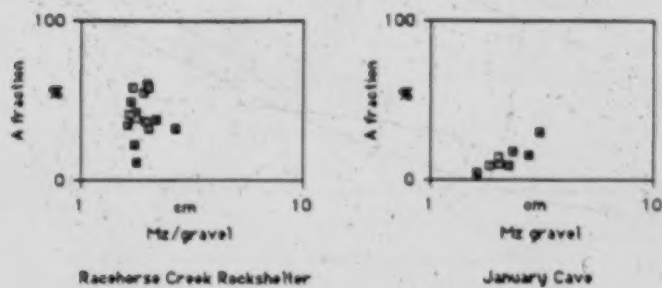


Figure 48. Sedimentological data for A and C fractions, January Cave.



Figure 49. Plot of the range of mean size and A fraction percentage values for January Cave and Racehorse Creek Rockshelter (RCRS).



Site	Correlation Coefficient
Racehorse Creek Rockshelter	$r = 0.029$
January Cave	$r = 0.861$

Figure 50. Scatterplot of mean size of the A fraction (Mzmm) versus percentage of the A fraction with their correlation coefficients (r).



Figure 51. Location map of the Bluefish Caves, northern Yukon

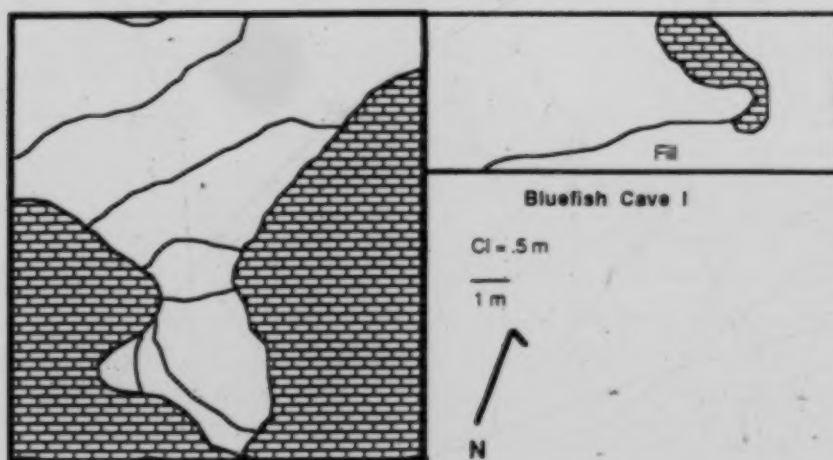


Figure 52. Planview and longitudinal cross-section of Bluefish Cave I (redrawn after Cinq-Mars 1979).

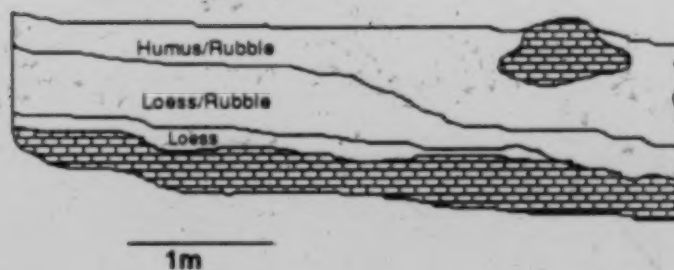


Figure 53. Schematic west wall profile of trench excavated in Bluefish Cave I.

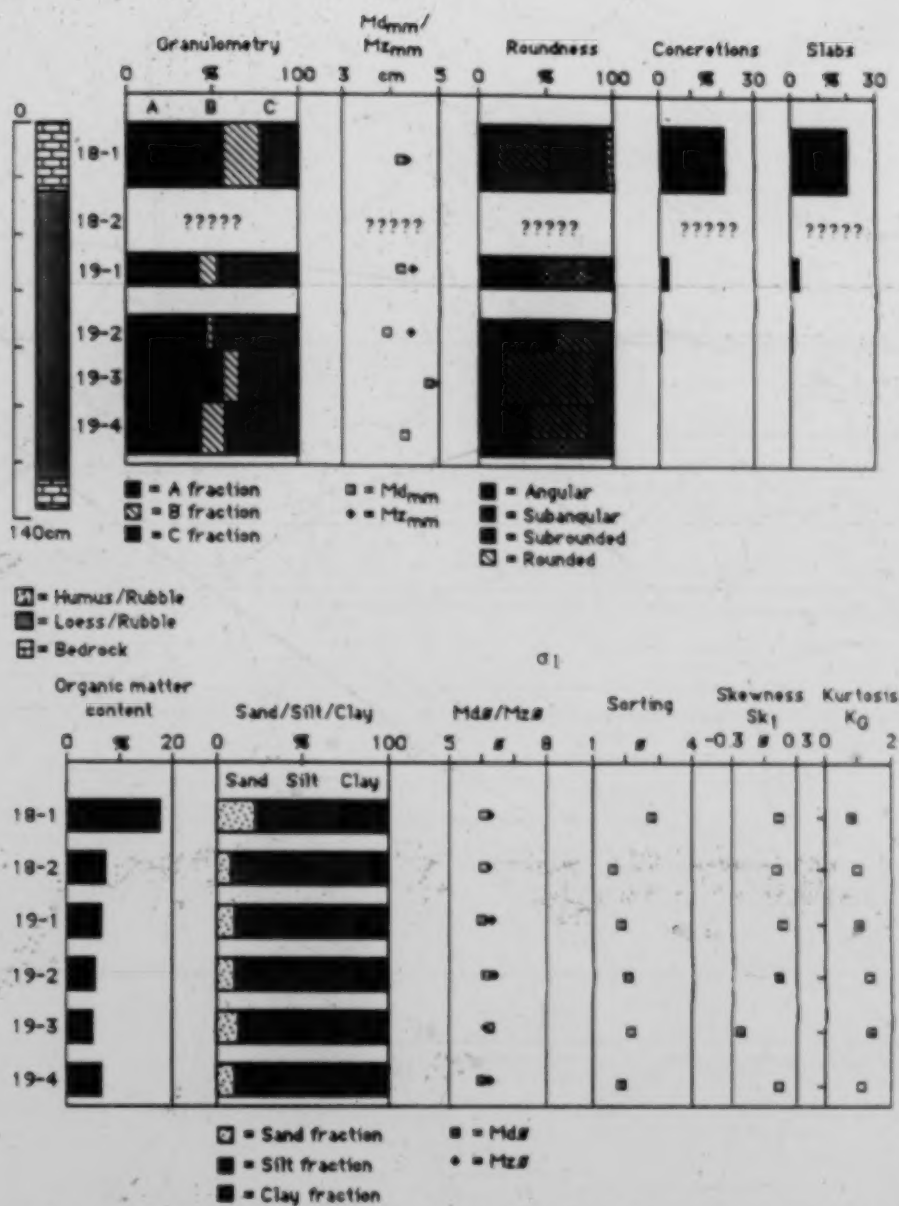
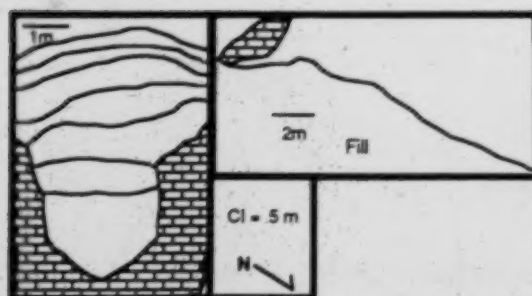


Figure 54. Sedimentological diagram of A fraction and C fraction for sediment samples from Bluefish Cave I. ???? = missing data. In upper diagram, the thickness of the histograms corresponds to the thickness of the sample taken.



Bluefish Cave II

Figure 55. Planview and longitudinal cross-section of Bluefish Cave II (redrawn from Cinq-Mars 1979)

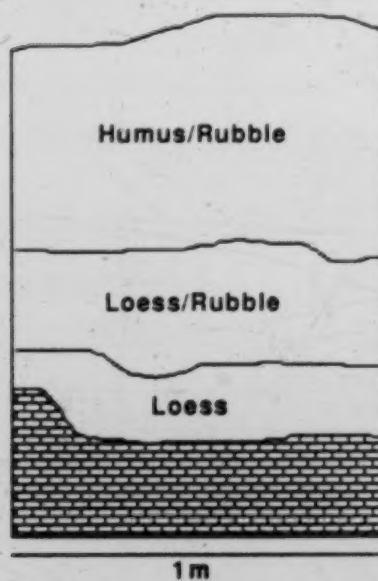


Figure 56. Profile of exposed sampled section at Bluefish Cave II.

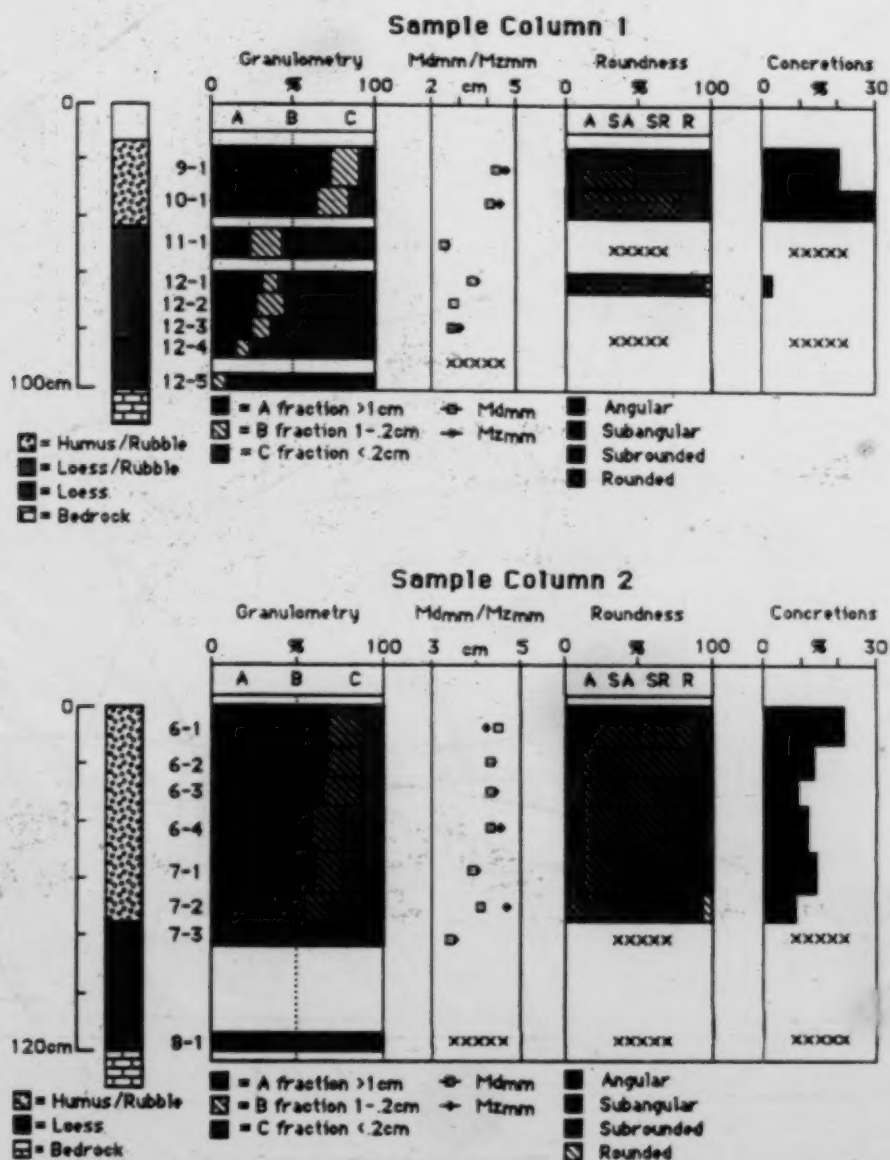


Figure 57. Sedimentological data for A fraction of sediment samples from Sample Column 1 and 2, Bluefish Cave II. Thickness of histogram corresponds to thickness of sample. xxxxx = insufficient data. ???? = missing data.

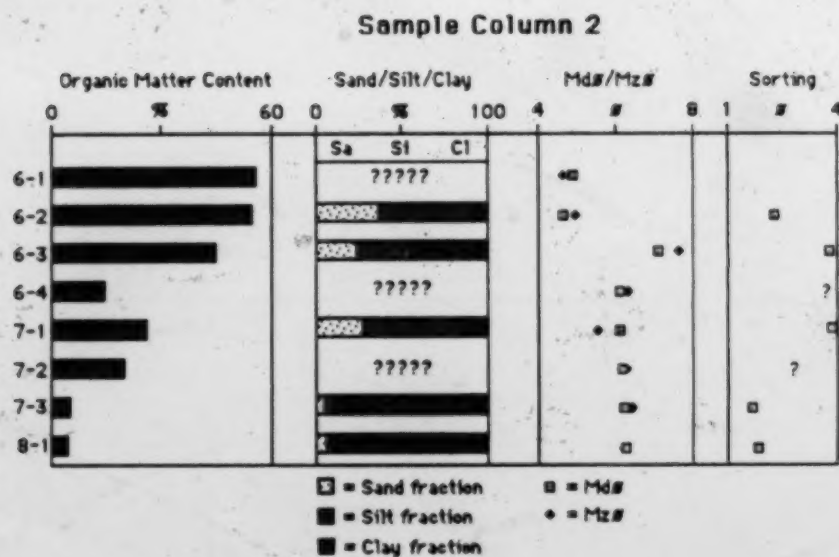
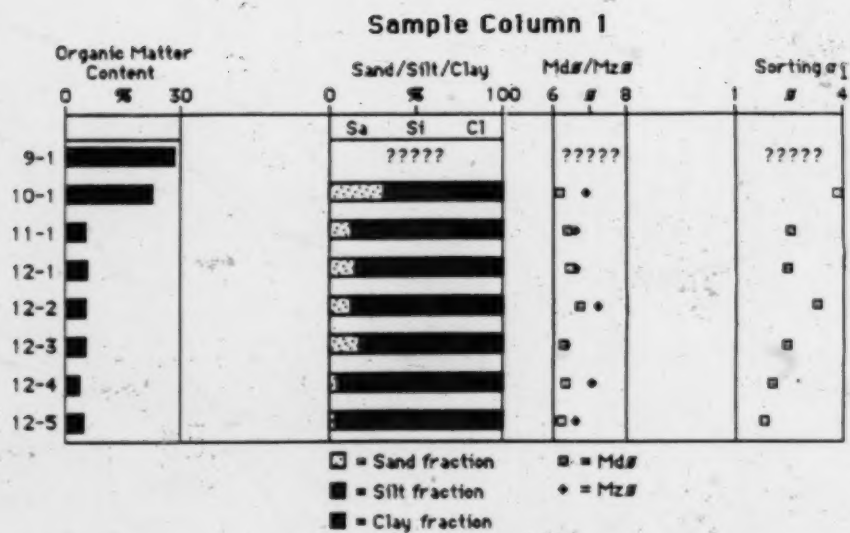


Figure 58. Sedimentological data for the C fraction of samples from sample columns 1 and 2, Bluefish Cave II.

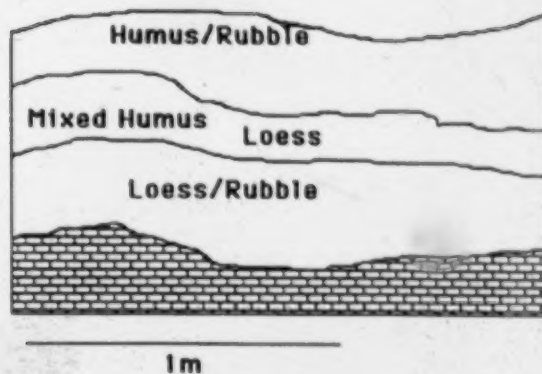
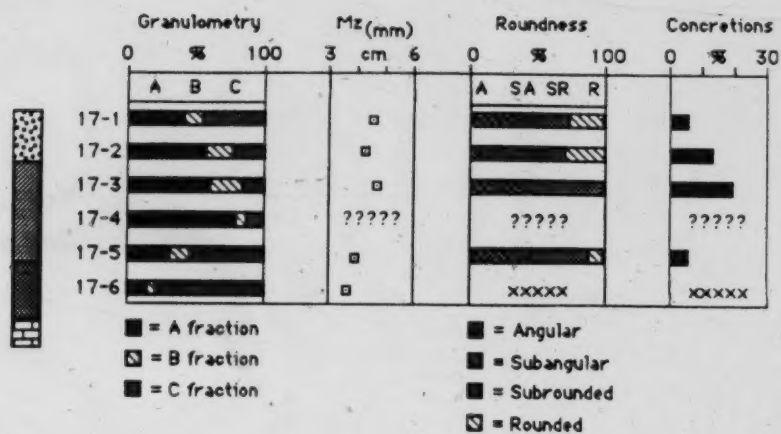


Figure 59. Lithostratigraphic section for Bluefish Cave III.

Sample Column 1



Sample Column 2

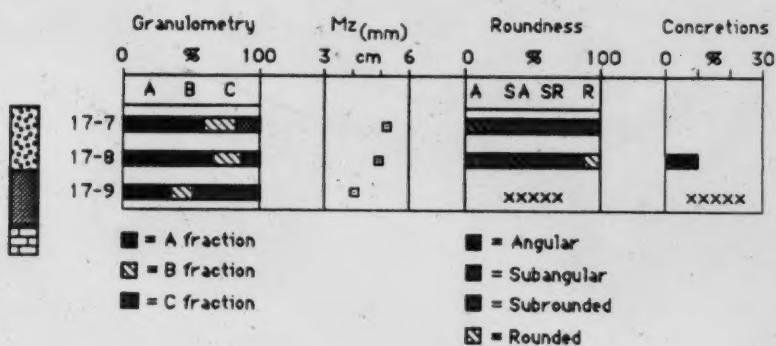
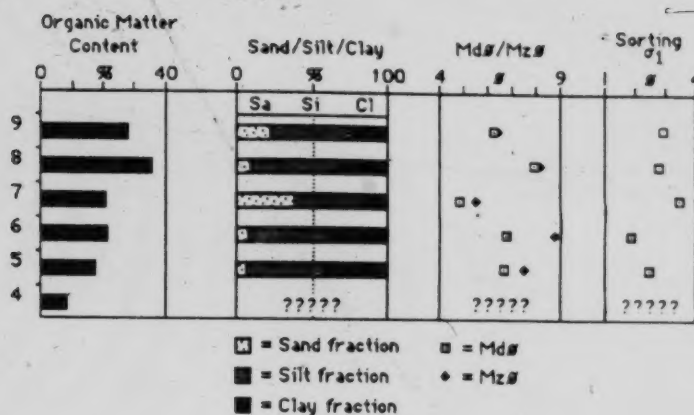


Figure 60. Sedimentological diagram for the A fraction in sample columns 1 and 2 at Bluefish Cave III. ???? = missing data. xxxxx = insufficient sample size.

Sample Column 1



Sample Column 2

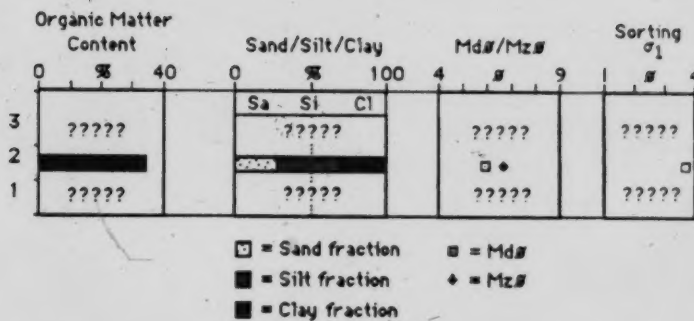


Figure 61. Sedimentological diagram for the C fraction of samples from sample columns 1 and 2 at Bluefish Cave III.

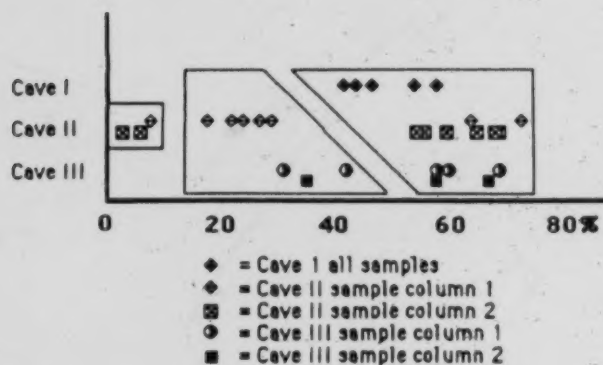


Figure 62. Comparison diagram of percent of sample >1cm in all samples from Bluefish Caves I, II and III. Small box on left side of diagram encloses loess samples. Middle polygon encloses suspected Loess/Rubble samples. Polygon on right encloses Humus/Rubble samples.

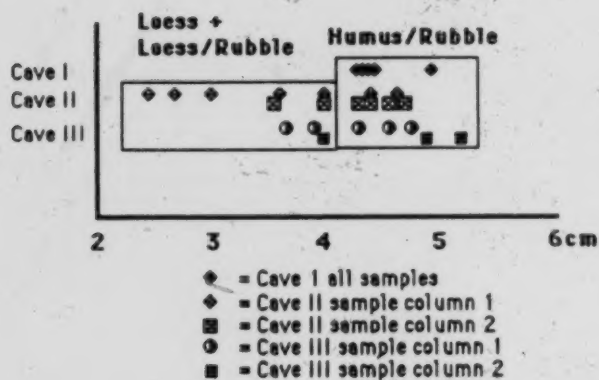
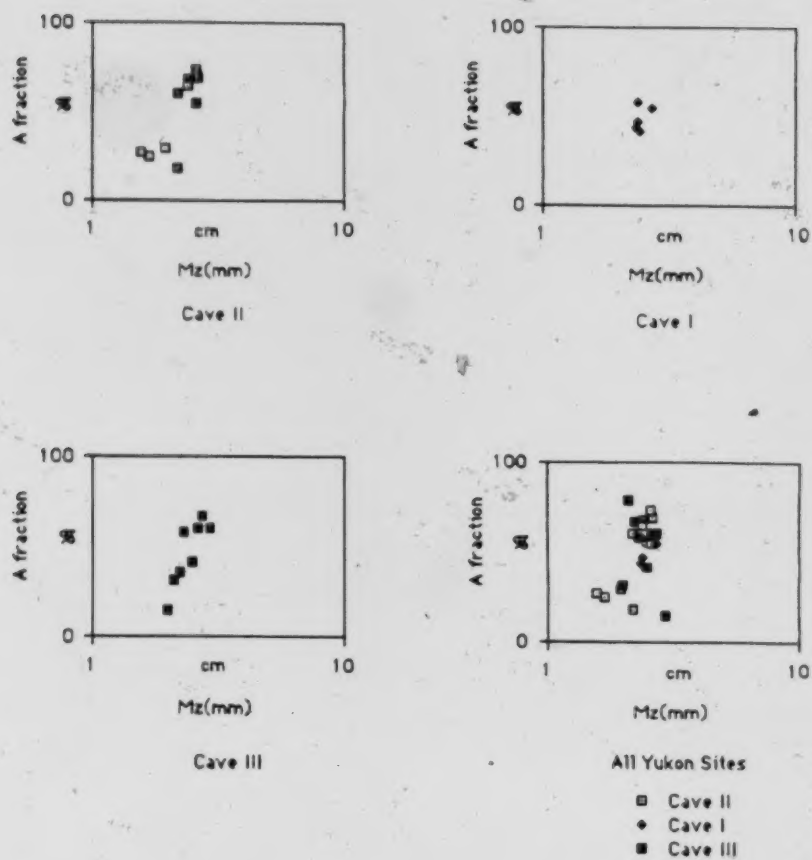


Figure 63. Comparison diagram of mean size (Mzmm) of A fraction clasts from Bluefish Caves 1, 2 and 3.



Site	Correlation Coefficient
Cave I	$r = 0.352$
Cave II	$r = 0.914$
Cave III	$r = 0.801$
All Sites	$r = 0.781$

Figure 64. Scatterplots of mean size (Mz) of A fraction clasts versus A fraction percentage for Yukon sites. Slope of best fit line and correlation coefficient (R) presented below.

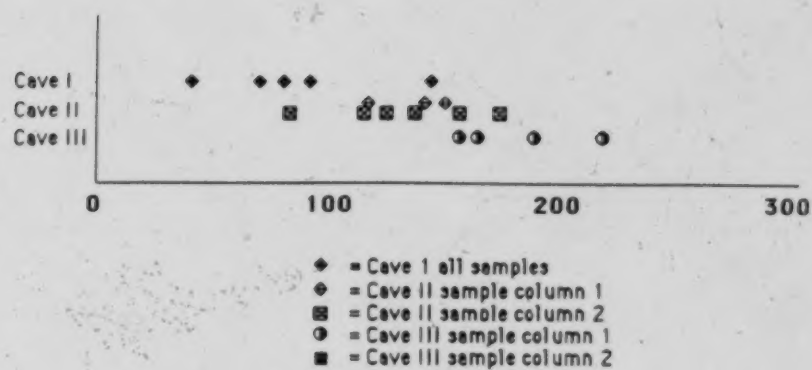


Figure 65. Comparison diagram of degree of roundness of clasts in all Bluefish Cave samples. Degree of roundness calculated using roundness index of Madeyski (1982).

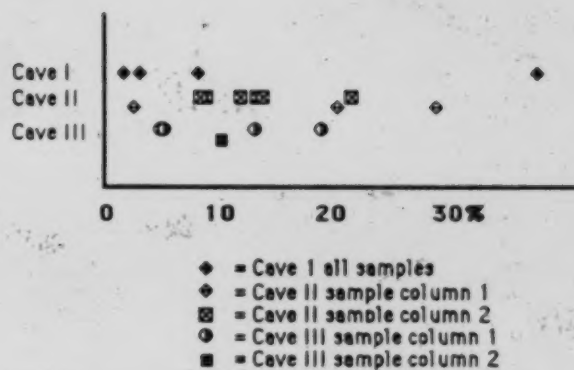


Figure 66. Comparison diagram of percentage of clasts exhibiting secondary carbonate concretions in samples from Bluefish Caves I, II and III.

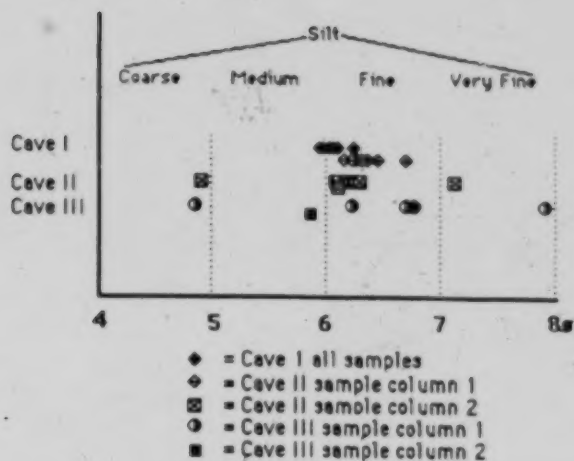


Figure 67. Comparison diagram of the median grain size (Mda) for sediment samples from all the Bluefish Caves.

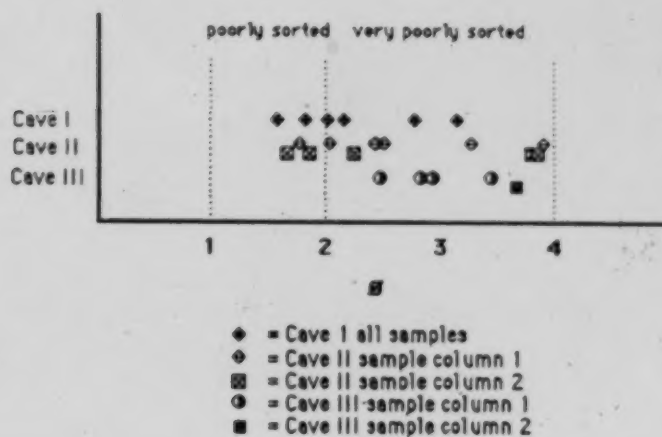


Figure 68. Comparison diagram of sorting (σ) for sediment samples from Bluefish Caves I, II and III.

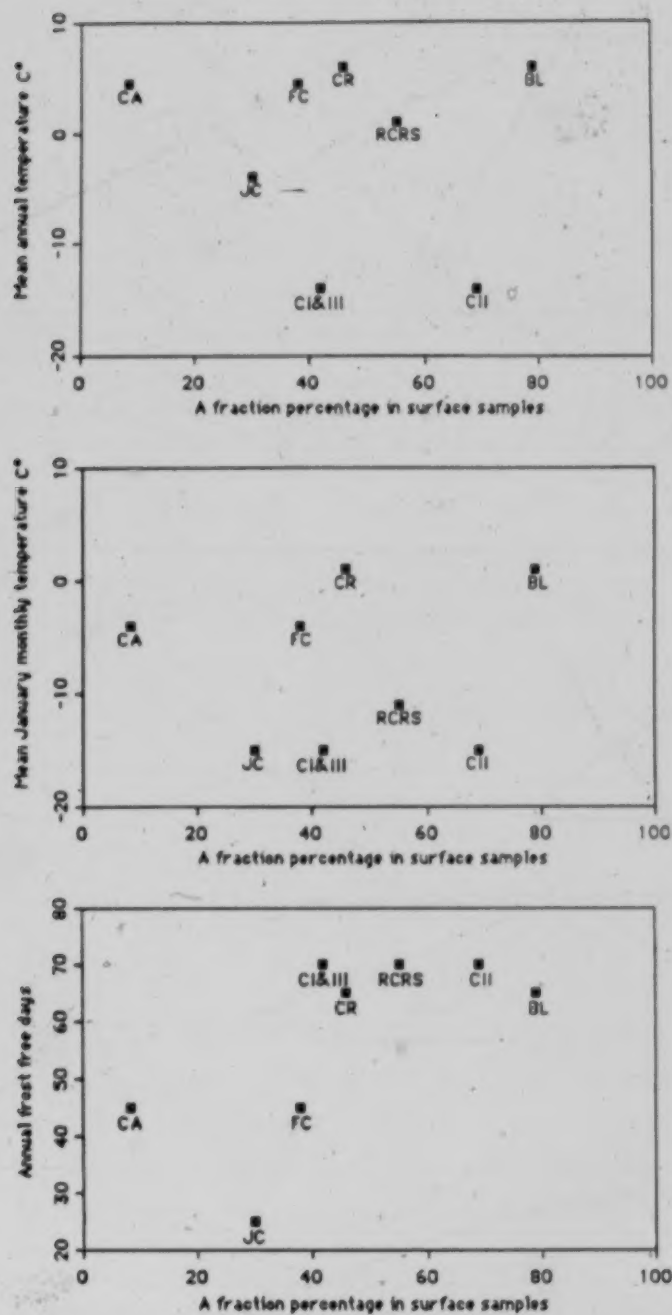


Figure 69. Scatterdiagram of the A fraction percentage for surface samples plotted against selected climatic parameters. CI, CII, CIII = Yukon caves; RCRS = Racehorse Creek Rockshelter; CR = Crystalsin Cave; JC = January Cave; FC = False Cougar Cave; CA = Cave Ann; BL = Big Lip Rockshelter.

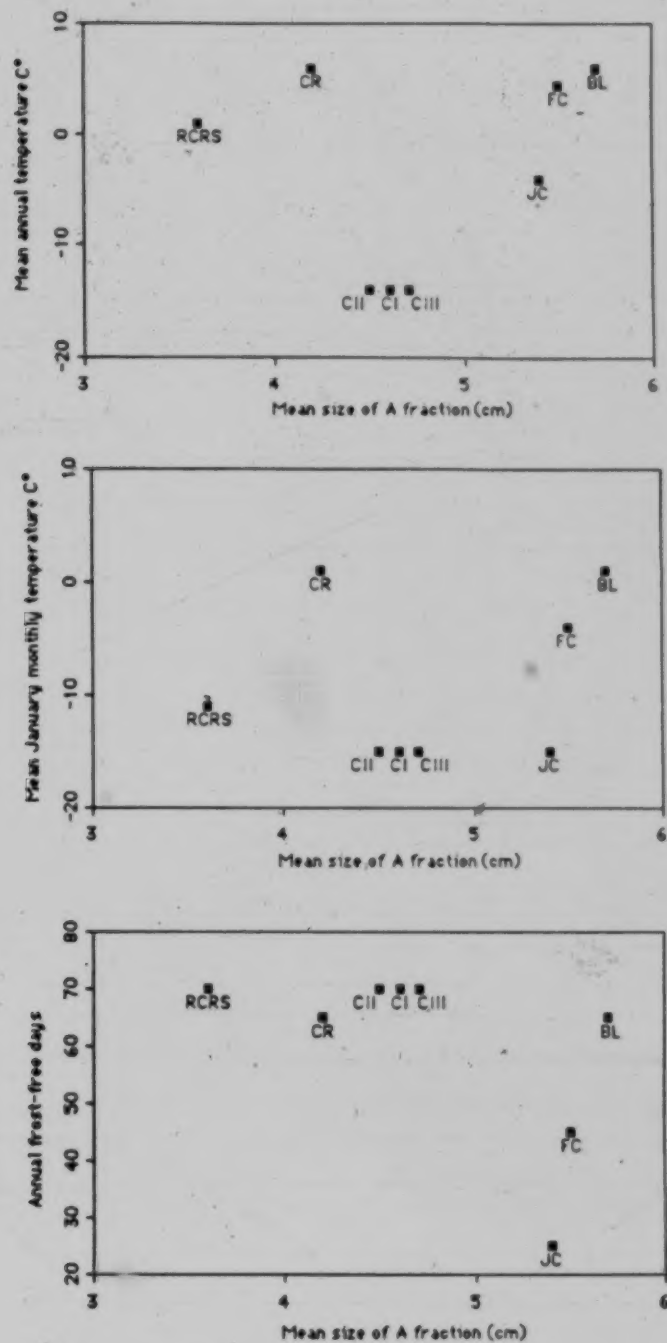


Figure 70. Scatterdiagram of the mean clast size for surface samples plotted against selected climatic parameters. CI, CII, CIII = Yukon caves; RCRS = Racehorse Creek Rockshelter; CR = Crystalsin Cave; JC = January Cave; FC = False Cougar Cave; BL = Big Lip Rockshelter.

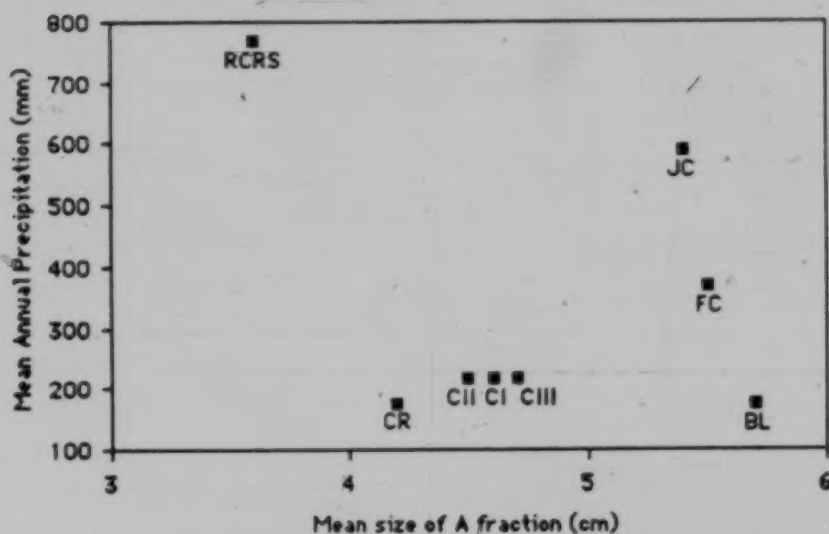
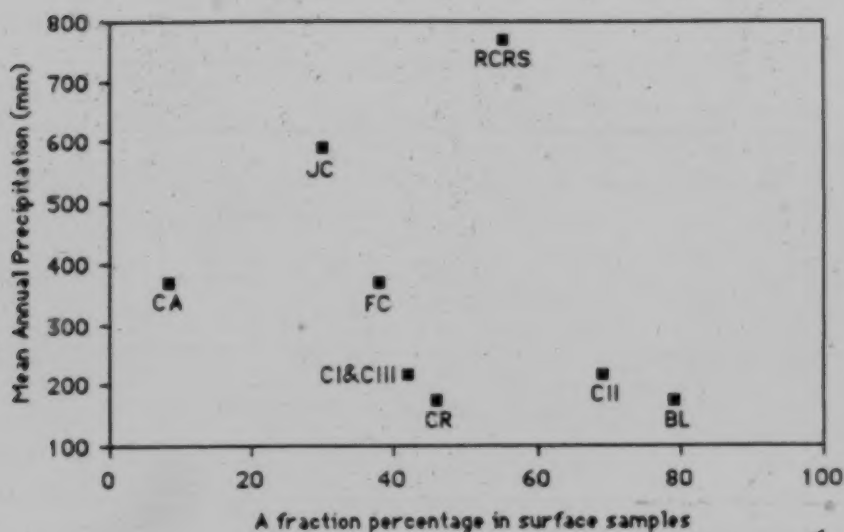


Figure 71. Scatterdiagram of the mean clast size and A fraction percentage for surface samples plotted against mean annual precipitation. CI, CII, CIII = Yukon caves; RCRS = Racehorse Creek Rockshelter; CR = Crystalsin Cave; JC = January Cave; FC = False Cougar Cave; CA = Cave Ann; BL = Big Lip Rockshelter.

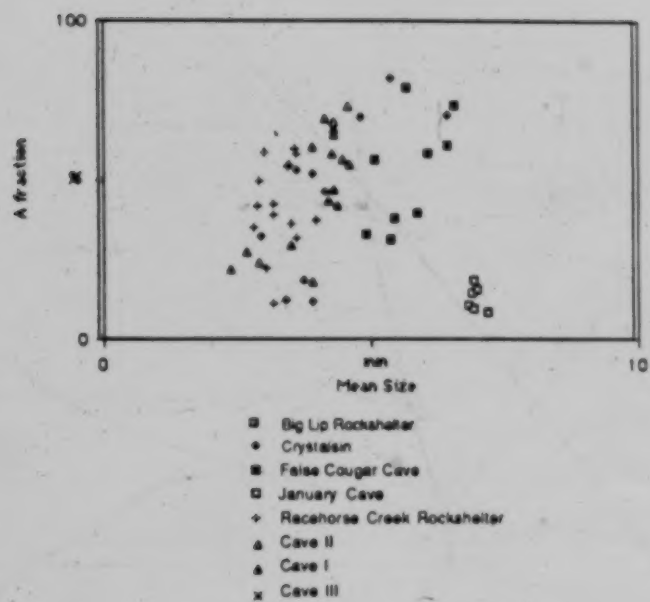


Figure 72. Scatterdiagram of percentage of A fraction vs. mean size of A fraction class. $r = 0.32$.

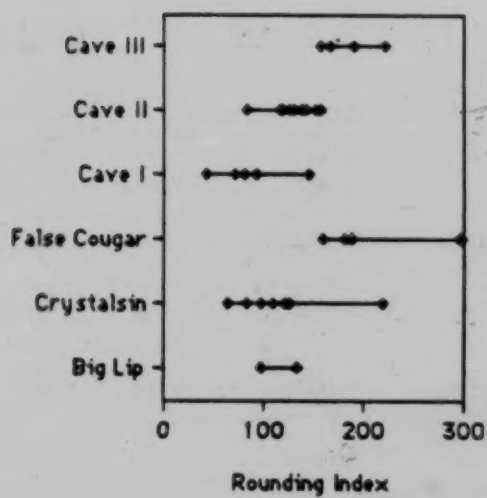


Figure 73. Comparison of rounding index (Madeyska 1982) between sites. Sites are ranked on y-axis in terms of increasing altitude (for Pryor Mountains) or increasing latitude.

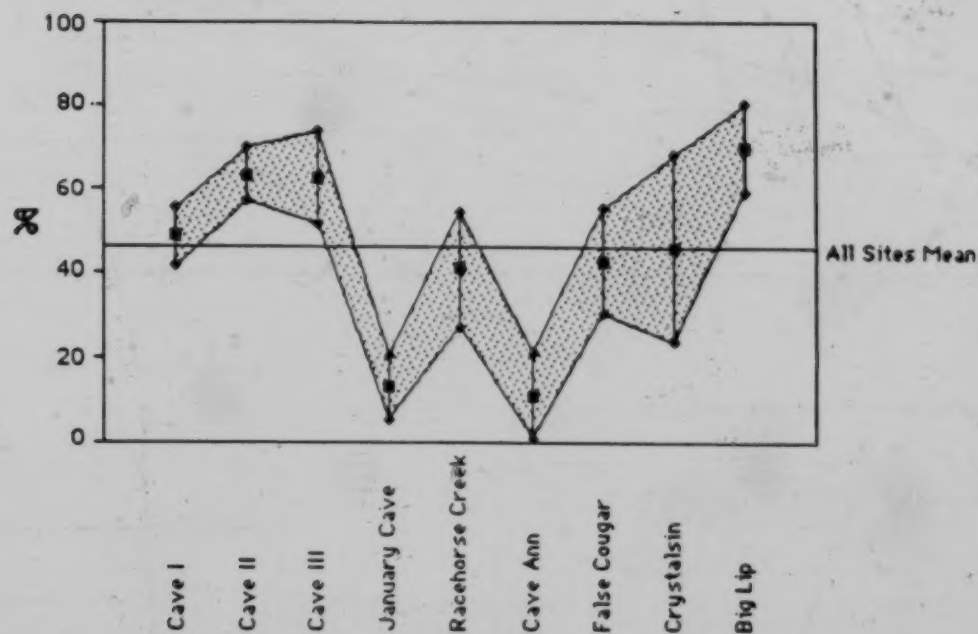


Figure 74. Plots of the mean and one standard deviation of the A fraction percentage for all samples from sites discussed in this study. The horizontal line is the mean of all samples from all sites.

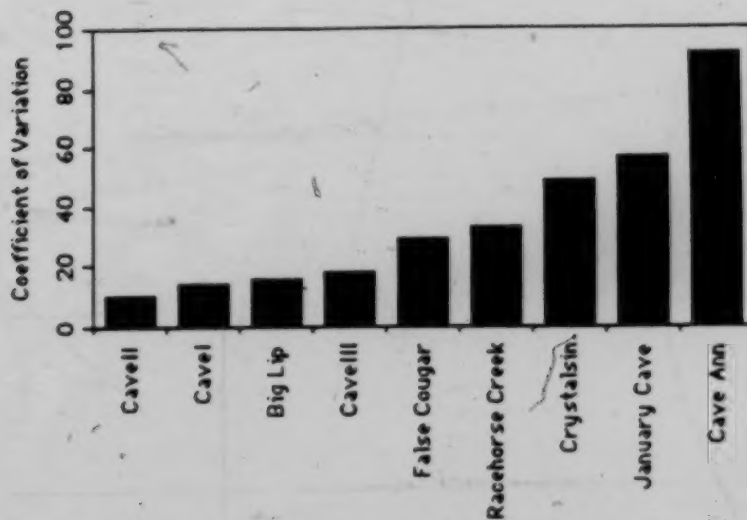


Figure 75. Coefficient of variation of A fraction percentages ranked from lowest to highest.



Figure 76. Coefficient of variation of mean size of A fraction clasts ranked from lowest to highest.

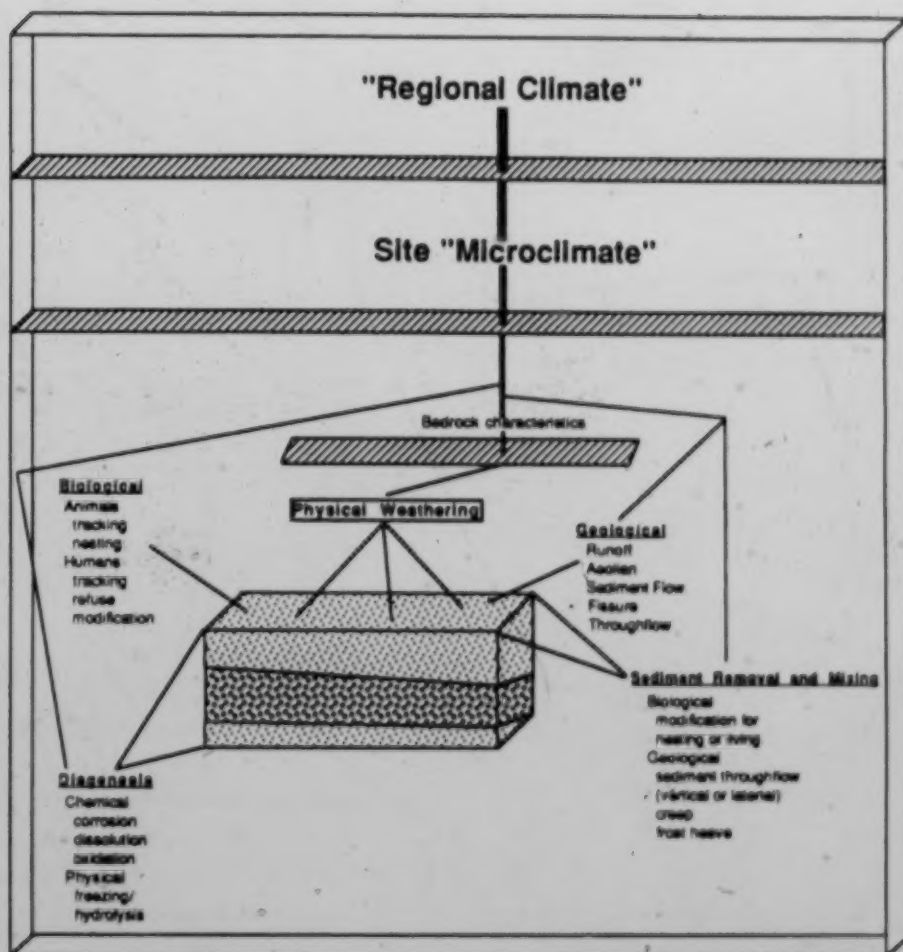


Figure 77. Model illustrating the relationship between a sediment accumulation, climate, and the myriad of factors controlling sedimentation, erosion, and diagenesis in a hypothetical cave or rockshelter. The horizontal shelves represent filters, modifying the influence of one level upon lower levels. The thickness of the connecting lines between levels also indicates the progressive decrease in the influence of upper level phenomena, such as regional climate, on lower level phenomena.

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